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Issued January 18, 1913.

U. S. DEPARTMENT OF AGRICULTURE,

FOREST SERVICE—BULLETIN 115.

HENRY S. GRAVES, Forester.

FOREST PRODUCTS LABORATORY SERIES.

MECHANICAL PROPERTIES OF WESTERN HEMLOCK.

BY

O. P. M. GOSS,

Engineer in Forest Products.

WASHINGTON:

GOVERNMENT PRINTING OFFICE.

1913.

FOREST SERVICE.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Forest Service,
Washington, D. C., August 28, 1912.

Sir: I have the honor to transmit herewith a manuscript entitled "Mechanical Properties of Western Hemlock," by O. P. M. Goss, Engineer in Forest Products, and to recommend its publication as Bulletin 115 of the Forest Service.

Respectfully,

Henry S. Graves,
Forester.

Hon. James Wilson,
Secretary of Agriculture.

Additional copies of this publication may be procured from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 15 cents per copy

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MECHANICAL PROPERTIES OF WESTERN HEMLOCK.

THE TREE.

This bulletin presents the results of mechanical tests made by the Forest Service upon western hemlock, and shows the general structural uses to which it is best adapted.

The tests were made at the Seattle Laboratory of the Forest Service, conducted in cooperation with the University of Washington, upon material donated by the Pacific Coast Lumber Manufacturers' Association. The Northern Pacific Railway Co. furnished free transportation for all material used in these tests.

Western hemlock is generally considered to be an inferior wood, especially in localities where it is not well known. A thorough investigation of its properties, however, proves this prejudice to be unfounded, and shows that it is entitled to take its place as one of the most important western woods.

Western hemlock (*Tsuga heterophylla*) is known under a variety of names in different localities. Lumbermen often give it some fictitious name which usually assists in marketing the lumber. Certain commercial organizations, however, are beginning to place hemlock on the market under its own name, and allowing it to be sold on its merit.

The common names in use are hemlock, western hemlock, hemlock spruce, western hemlock spruce, western hemlock fir, Prince Albert fir, gray fir, and Alaska pine. The names gray fir and Alaska pine are favorite ones among lumbermen of the Pacific Northwest, while in England western hemlock fir and Prince Albert fir are used.

Western hemlock is found along the Pacific coast from Alaska to northern California, and as far inland as British Columbia, northern Idaho, and northwestern Montana. Figure 1 shows its range. The best stands are found in the coast region and through the Cascade Mountains at an elevation of from 1,500 to 3,500 feet. In the State of Washington western hemlock forms approximately 13 per cent of the entire timber supply.

Mature trees reach a diameter of from 2 to 5 feet, and attain a height of from 125 to 150 feet. Exceptional trees have measured 8 feet in diameter and 250 feet in height. The heartwood is almost

white in color. The yellowish white sapwood forms a very small percentage of the trunk, and is generally not over 1 inch in thickness. The green wood has a decidedly sour odor, which, however, disappears in seasoned material.

The structure of the wood in transverse, radial, and tangential sections is shown in Plates I, II, and III, respectively, in which the wood fiber is magnified 50 times. The wood is made up principally of fibers running lengthwise with the trunk. At right angles to the fibers are the pith rays, which lie in radial planes. Resin cells also occur, usually in the summerwood. Plate I shows the wood formed in a season's growth. The transition from springwood formed in the early part of the growing season to summerwood is very gradual.

Fig. 1.—Range of western hemlock.

MATERIAL TESTED.

The material upon which the tests were made was selected from regions where western hemlock is found in abundant stands. All of the timbers tested were cut in the State of Washington, either about Grays Harbor or about Buckley.

The Grays Harbor shipment was cut about 20 miles from the coast at an elevation between 500 and 1,000 feet. The Buckley shipment was cut about 100 miles from the coast at an elevation between 1,000 and 1,500 feet. The timbers were selected at the mills of the Western Lumber Co. at Aberdeen, Wash., and at the St. Paul & Tacoma Lumber Co.'s mill at Tacoma, Wash.

Both shipments were received at the laboratory in a green condition. The timbers were graded by an experienced inspector in accordance with the export rules of the Pacific Coast Lumber Manufacturers' Association. Half of the pieces were tested while green and the other half stacked in an open pile under shelter and allowed to air season before being tested. (Pl. VI.)

The tests were made on two general classes of material:

(1) Structural timbers, such as are found on the market, and representative of the various commercial grades. This material consisted of 8 by 16 inch by 16-foot bridge stringers.

(2) Small clear pieces cut from the uninjured portions of the tested bridge stringers. Such pieces were tested to show the various relations which exist between the mechanical and physical properties of the clear wood.

METHODS OF TEST.[1]

BENDING.

All bending tests of seasoned bridge stringers were made on a span of 15 feet, and the load was applied at two points, each one-third the length of the span from the end supports. This method is called "third-point loading." Thirty of the green stringers were tested over a span of 15 feet 6 inches and were loaded at the center of the span, while 15 were tested under third-point loading over a span of 15 feet. In the early tests made by the Forest Service on bridge stringers center loading was used. This method has been changed, however, and now all large tests are made under third-point loading in order to make the test conditions more like those found in practice. All small beams were tested under center loading.

Four factors were calculated from the data derived from each bending test, all in terms of pounds per square inch:

(*a*) Fiber stress at elastic limit. This is the greatest stress that can occur in a beam loaded with an external load from which it will recover without permanent deflection.

(*b*) Modulus of rupture. This is the greatest computed stress in a beam loaded with a breaking load.

(*c*) Modulus of elasticity. This is a factor computed from the relation between load and deflection within the elastic limit and represents the stiffness of the wood fiber.

(*d*) Longitudinal shear. This is the stress tending to split the beam lengthwise along its neutral plane[1] when under maximum load.

COMPRESSION PARALLEL TO GRAIN.

Two sizes of specimens were used in the test in compression parallel to the grain, 6 by 6 by 24 inches and 2 by 2 by 8 inches. The specimens were set upright on the platform of the testing machine and the movable head of the machine forced down upon them until crushing occurred. Observations were made of the amount of load and

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[1] The methods which were used in testing western hemlock are in accordance with Forest Service standards and are fully described in Circular 38, "Instructions to Engineers of Timber Tests," Revised. Forest Service Bulletin 88, "Properties and Uses of Douglas Fir," by McGarvey Cline and J. B. Knapp, and Bulletin 108, "Tests of Structural Timbers," by McGarvey Cline and A. L. Heim, also describe the tests commonly made and give illustrations of the testing machines.

deflection (compression), and three factors analogous to three of those obtained in the bending tests were calculated:

(*a*) Compressive strength at elastic limit.
(*b*) Crushing strength at maximum load.
(*c*) Modulus of elasticity.

COMPRESSION PERPENDICULAR TO GRAIN.

Two sizes of specimens were used also in the tests in compression perpendicular to the grain, 8 by 16 by 30 inches and 6 by 6 by 24 inches. The tests were made by laying each block on its side on the platform of the machine and applying pressure to a steel plate resting on the block's upper side. Readings of the load and the corresponding deflection or crushing were taken up to and slightly beyond the elastic limit. From the data secured the compressive strength at elastic limit in pounds per square inch was calculated.

SHEARING.

The shearing tests were made on small clear blocks with a projecting lip 2 by 3 inches in section. The blocks were firmly held and the lip sheared off parallel to the grain. The load required to shear off the lip was calculated in pounds per square inch.

SHRINKAGE.

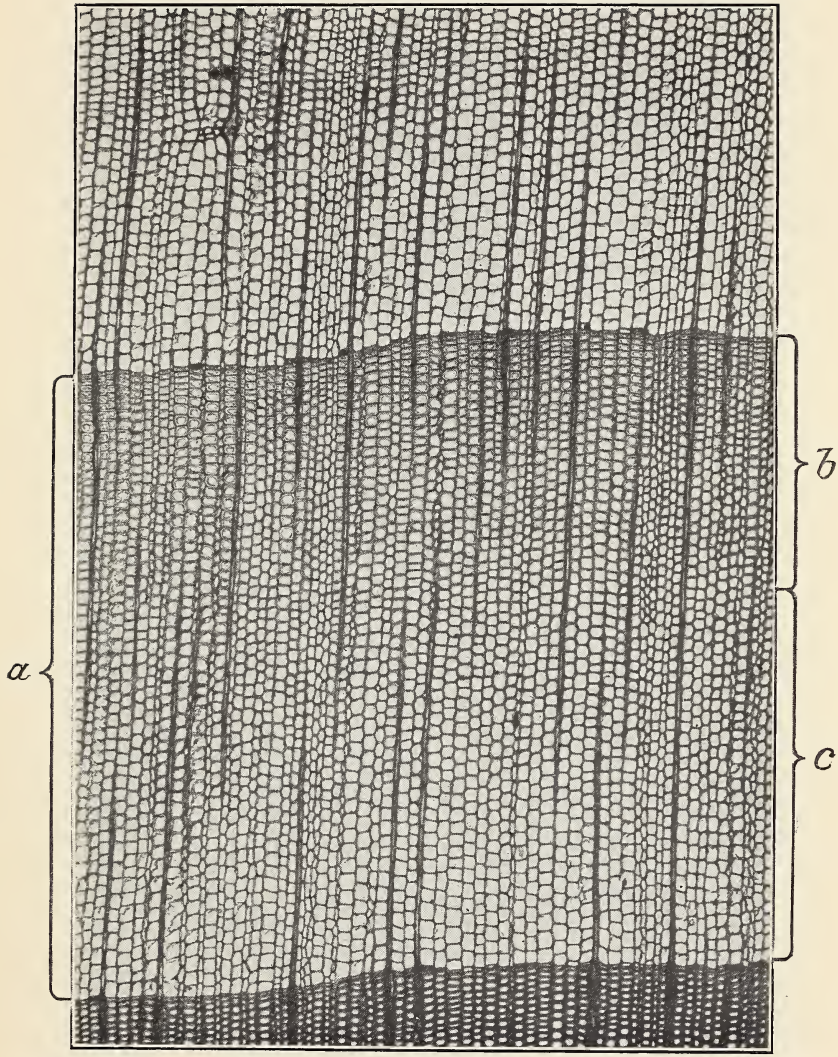
Shrinkage tests were made on both large and small specimens. Weights and measurements on a number of the large beams were taken from time to time in order to determine the rate of seasoning and the resulting amount of shrinkage which occurred. These measurements were continued until the timbers had passed from the green to the air-seasoned condition.

With the small specimens weighings and caliper measurements were made at intervals while the pieces were passing from a green to a bone-dry condition, and the total radial, tangential, and longitudinal shrinkage was determined. The thoroughly dried sticks were then allowed to absorb moisture from the air, and were finally brought to a saturated state by soaking. During the periods of absorption measurements and weights were taken at intervals and the amount of swelling determined.

MOISTURE DETERMINATIONS.

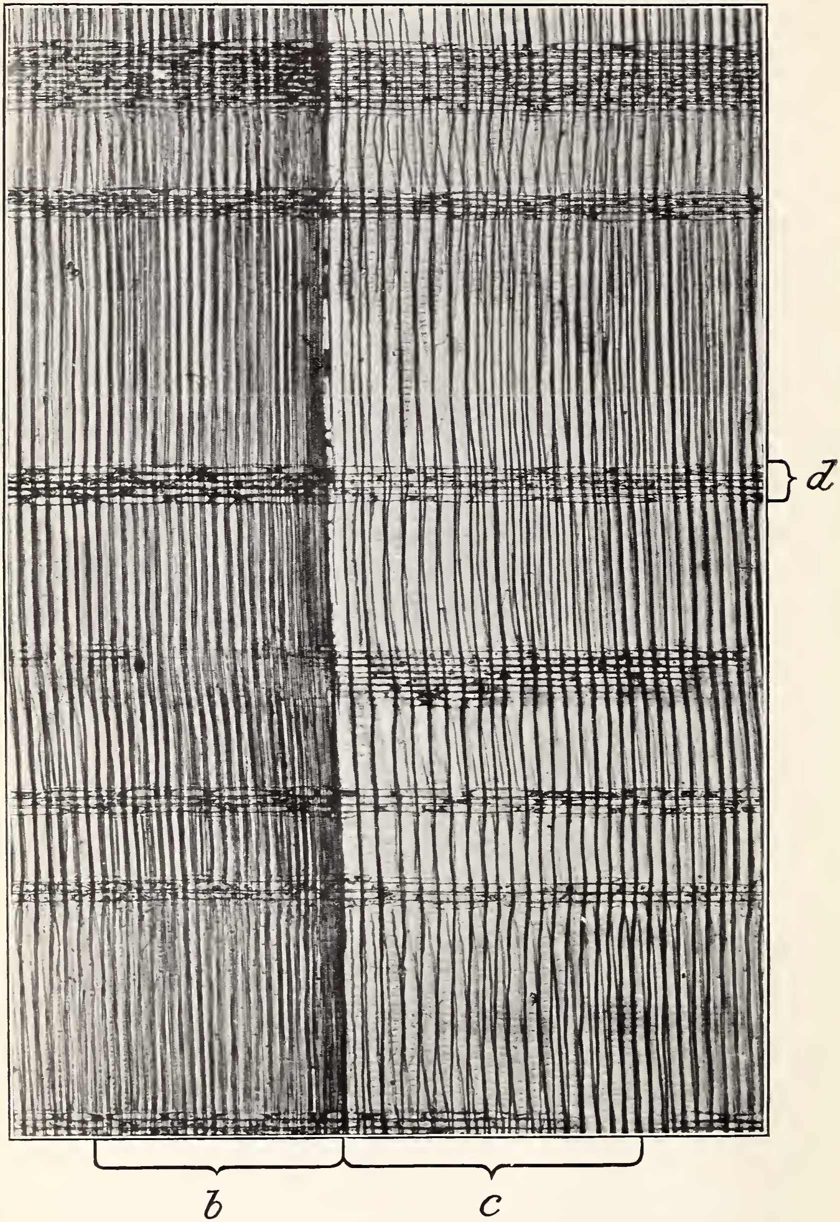
Immediately after each test sections about 1 inch in thickness were cut from the region of failure and weighed. These sections were then dried to constant weight at 100° C. In the case of bridge stringers

[1] Plane between upper and lower halves when beam is horizontal.



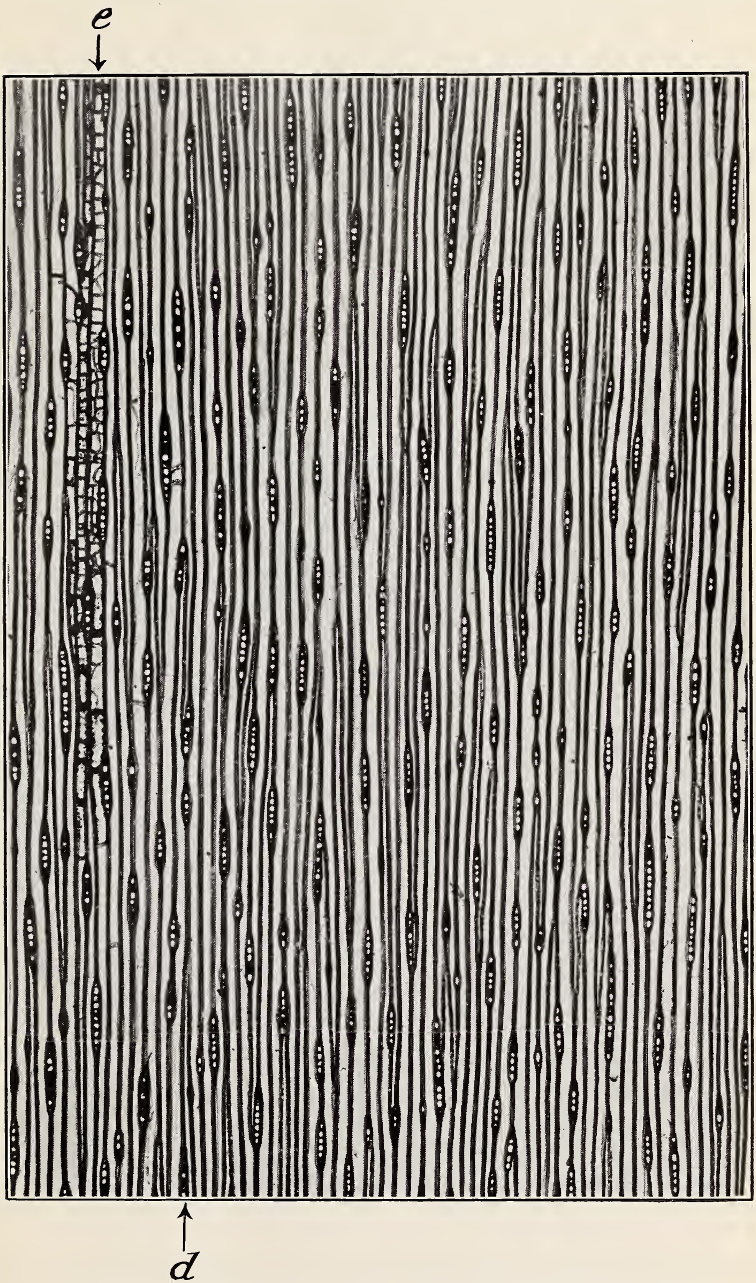
TRANSVERSE SECTION OF WESTERN HEMLOCK MAGNIFIED 50 TIMES.

a, annual rings; *b*, summerwood; *c*, springwood.



RADIAL SECTION OF WESTERN HEMLOCK MAGNIFIED 50 TIMES.

b, summerwood; *c*, springwood; *d*, pith ray.



TANGENTIAL SECTION OF WESTERN HEMLOCK MAGNIFIED 50 TIMES.

d, pith ray; *e*, resin cell.

the distribution of moisture throughout the section was also determined. The moisture percentages given are based on the dry weight of the wood.

GENERAL TEST OBSERVATIONS.

All test pieces were weighed and measured and the number of rings counted on a radial line. Sketches were made showing the size and location of knots, checks, and shakes. The proportion and location of sapwood was also noted.

AVERAGE VALUES.[1]

Table 1 shows average strength values determined from tests made by the Forest Service on structural forms and on small, clear sticks cut from the large pieces after test. The various species represented are those most commonly used in construction work. The longleaf-pine timbers tested were partially seasoned; consequently the strength values given are slightly greater than would be found in thoroughly green wood. The test material from all other species was thoroughly green.

Table 2 shows average strength values obtained from tests on western hemlock stringers and on small, clear sticks cut from them. Values for both green and seasoned material are given, and also the ratios of the strength factors of seasoned to green pieces. The results of the different tests are shown in more detail in Tables 12 to 14.

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[1] In the following summaries and figures the weight per cubic foot is based on the volume of the specimen when tested. If the dry weight per cubic foot is calculated for a green timber, and later this timber is allowed to air season, and a second dry weight per cubic foot computed, these two determinations will be different. An error is introduced, due to the shrinkage which occurs in the timber in passing from the green to the air-seasoned condition. It is therefore necessary in comparing the dry weight per cubic foot calculated from green and air-seasoned timbers to consider the shrinkage which occurs in seasoning. On pages 28 to 31 shrinkage is discussed and figures are given which permit the dry weights of wood calculated from pieces in various conditions of moisture to be reduced to the same basis.

In all diagrams the numbers near the points through which the curves are drawn indicate the number of tests averaged for the respective points.

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TABLE 1.—*Average strength values for various species; green structural timbers and small pieces without defects.*

Species.	Weight per cubic foot, oven dry.	Rings per inch.	Bending.					Compression parallel to grain.			Compression perpendicular to grain.	Shear.
			Number of tests.	Fiber stress at elastic limit per square inch.	Modulus of rupture per square inch.	Modulus of elasticity per square inch.	Horizontal shear per square inch.(1)	Compressive strength at elastic limit per square inch.	Crushing strength at maximum load per square inch.	Modulus of elasticity per square inch.	Compressive strength at elastic limit per square inch.	Shearing strength per square inch.
	Pounds.			*Pounds.*	*Pounds.*	*1,000 lbs.*	*Pounds.*	*Pounds.*	*Pounds.*	*1,000 lbs.*	*Pounds.*	*Pounds.*
Longleaf pine:												
Structural sizes	35	13.8	17	3,734	6,140	1,463	353	3,480	4,800		568	
Small specimens			15	4,950	9,070	1,540			4,400			973
Ratio				.75	.68	.95			1.09			
Douglas fir:												
Structural sizes	28	11.0	191	3,963	5,983	1,517	166	2,770	3,495	1,414	570	
Small specimens			568	5,227	8,280	1,597		3,500	4,030	1,925		765
Ratio				.76	.72	.95		.79	.87	.74		
Shortleaf pine:												
Structural sizes	30	12.1	48	3,237	5,548	1,473	332	2,460	3,435	1,548	351	
Small specimens			254	4,350	7,710	1,395			3,570		400	704
Ratio				.74	.72	1.06			.96		.88	
Western larch:												
Structural sizes	28	24.3	62	3,325	4,918	1,300	288	2,674	3,509	1,575	456	
Small specimens			189	4,274	7,251	1,310		3,026	3,696	1,545		700
Ratio				.78	.68	.99		.88	.95	1.02		
Loblolly pine:												
Structural sizes	31	5.9	111	3,040	5,084	1,387	335	2,050	2,940	548	500	
Small specimens			44	4,100	7,870	1,440			3,240			630
Ratio				.74	.65	.96			.91			
Tamarack:												
Structural sizes	30	14.0	30	2,813	4,556	1,220	261	2,400	3,230	1,373		
Small specimens			82	3,875	6,820	1,141			3,190			668
Ratio				.73	.67	1.07			1.01			
Western hemlock:												
Structural sizes	27	15.6	39	3,516	5,295	1,445	288	2,910	3,400	1,619	465	
Small specimens			52	4,406	7,294	1,428		2,938	3,392	1,737		630
Ratio				.80	.73	1.01		.99	1.00	.93		

Redwood:												
Structural sizes	22	18.8	28	3,760	4,472	1,042	302	3,194	3,882	1,240	434	....
Small specimens	....	....	157	4,750	6,980	1,061	....	3,490	3,930	1,222	569	742
Ratio	....	....	....	.79	.64	.98	....	.92	.98	1.01	.76	....
Norway pine:												
Structural sizes	25	13.7	49	2,492	3,864	1,133	232	2,065	2,555	1,002	....	....
Small specimens	....	....	133	2,808	5,173	960	....	....	2,504	....	....	589
Ratio	....	....	....	.89	.75	1.18	....	....	1.02	....	....	....

1 Only those pieces which failed first by horizontal shear are included in this column.

TABLE 2.—*Average strength values for green and air-seasoned western hemlock in structural sizes and for small pieces without defects.*

GREEN MATERIAL.

	Bending.							Compression parallel to grain.						Compression perpendicular to grain.			Shear.		
Cross section.	Number of tests.	Rings per inch.	Per cent moisture.	Weight per cubic foot, oven dry.	Fiber stress at elastic limit per square inch.	Modulus of rupture per square inch.	Modulus of elasticity per square inch.	Size of specimen	Number of tests.	Per cent moisture.	Compressive strength at elastic limit per square inch.	Crushing strength at maximum load per square inch.	Modulus of elasticity per square inch.	Number of tests.	Per cent moisture.	Compressive strength at elastic limit per square inch.	Number of tests.	Per cent moisture.	Shearing strength per square inch.
Inches.				*Pounds.*	*Pounds.*	*Pounds.*	*1,000 lbs.*	*Inches.*			*Pounds.*	*Pounds.*	*1,000 lbs.*			*Pounds.*			*Pounds.*
8 x 16	39	15.6	42.5	27.3	3,516	5,295	1,445	6 x 6 x 24	82	46.6	2,910	3,400	1,619	48	46.2	465	54	65.7	630
2 x 2	52	12.1	51.8	26.3	4,406	7,294	1,428	2 x 2 x 8	131	55.6	2,938	3,392	1,737						
AIR-SEASONED MATERIAL.																			
8 x 16	44	17.8	17.7	27.8	4,398	6,420	1,737	6 x 6 x 24	102	18.5	4,840	5,800	2,141	58	17.3	475	131	17.7	924
2 x 2	311	19.4	17.9	27.6	6,333	10,369	1,666	2 x 2 x 8	463	17.0	4,560	5,403	1,923						
RATIO, AIR-SEASONED TO GREEN.																			
8 x 16					1.25	1.21	1.20	6 x 6 x 24			1.67	1.71	1.32			1.02			1.47
2 x 2					1.44	1.42	1.17	2 x 2 x 8			1.55	1.59	1.11						

VARIABILITY OF RESULTS.

To determine the reliability of average results from tests on a material such as wood, the variation of individual results from the average must be considered. Table 3 shows how the various results for the different tests vary from the average values. The column to the left indicates the range in per cent of the average values. The percentage of the total number of tests falling within any given range is shown in the other columns. This table shows also the number of tests of each kind made, the average values for each factor, and the percentage of the total number of tests which fall above and below the average. The results of all tests on green material were used in this table.

TABLE 3.—*Variation of the different strength factors from their average values.*

Kind of test	Bending.				Compression parallel to grain.		Compression perpendicular to grain.	Shearing.
Kind of specimen	Stringers.			Small clear.	Large, ordinary defects.	Small clear.	Large clear.	Small clear.
Size of specimen	8x16 inches x 16 feet.			2x2x30 inches.	6x6x24 inches.	2x2x8 inches.	8x16x30 inches and 6x6x24 inches.	2x3 inches.
Strength factors	Fiber stress at elastic limit.	Modulus of rupture.	Modulus of elasticity.	Modulus of rupture.	Maximum crushing strength.	Maximum crushing strength.	Crushing strength at elastic limit.	Shearing strength.
Number of tests	39	39	39	52	82	127	48	54
Average values—pounds per square inch	3,516	5,295	1,445,000	7,294	3,353	3,392	465	630
Per cent of total number of tests that fell above the average	59	59	54	46	54	46	46	52
Per cent of total number of tests that fell below the average	41	41	46	54	46	54	54	48
Distribution of individual tests with regard to the average—in per cent of total number of tests:								
Between 165 and 170 per cent of average	...	...	...	...	...	...	...	...
Between 160 and 165 per cent of average	...	...	...	...	...	...	1	...
Between 155 and 160 per cent of average	...	...	...	...	...	...	1	...
Between 150 and 155 per cent of average	...	...	...	...	...	...	1	...
Between 145 and 150 per cent of average	...	...	...	...	...	...	4	...
Between 140 and 145 per cent of average	...	...	...	2	...	...	1	2
Between 135 and 140 per cent of average	...	...	...	1	...	...	1	2
Between 130 and 135 per cent of average	...	8	...	0	...	3	0	2
Between 125 and 130 per cent of average	9	1	...	1	...	1	1	2
Between 120 and 125 per cent of average	2	2	7	3	2	3	4	4
Between 115 and 120 per cent of average	5	7	2	9	2	7	12	1
Between 110 and 115 per cent of average	12	12	8	10	12	6	8	1
Between 105 and 110 per cent of average	10	11	7	5	14	10	2	8
Between 100 and 105 per cent of average	21	18	30	15	24	16	10	30

Between 95 and 100 per cent of average	3	8	15	16	22	19	8	13
Between 90 and 95 per cent of average	17	7	10	15	10	14	14	14
Between 85 and 90 per cent of average	6	5	13	13	7	10	4	9
Between 80 and 85 per cent of average	3	7	2	5	2	5	2	5
Between 75 and 80 per cent of average	5	4	6	1	1	4	11	5
Between 70 and 75 per cent of average	0	1		1	2	0	11	2
Between 65 and 70 per cent of average	1	1		1	2	2	4	
Between 60 and 65 per cent of average	1	1		2				
Between 55 and 60 per cent of average	5	3						
Between 50 and 55 per cent of average		4						
Between 45 and 50 per cent of average								
Between 40 and 45 per cent of average								
Between 35 and 40 per cent of average								

The variation from the average value is greatest for the modulus of rupture of large beams and for compressive strength at elastic limit in compression perpendicular to grain. It may be concluded, therefore, that the modulus of rupture is readily influenced by disturbing factors, such as ordinary defects. The great variation in the comprehensive strength at elastic limit is not surprising, since some of the blocks had edge grain (rings vertical), some flat grain (rings horizontal), and others intermediate grain. Edge-grain wood when tested in side bearing is considerably stronger than similar wood tested with the grain flat. The results show what may be expected in the case of large timbers in which the position of the grain or rings in the bearing surface varies according to the way the beams are cut from the logs.

Least variation from the average values is found in the small-beam tests and in tests in compression parallel to the grain.

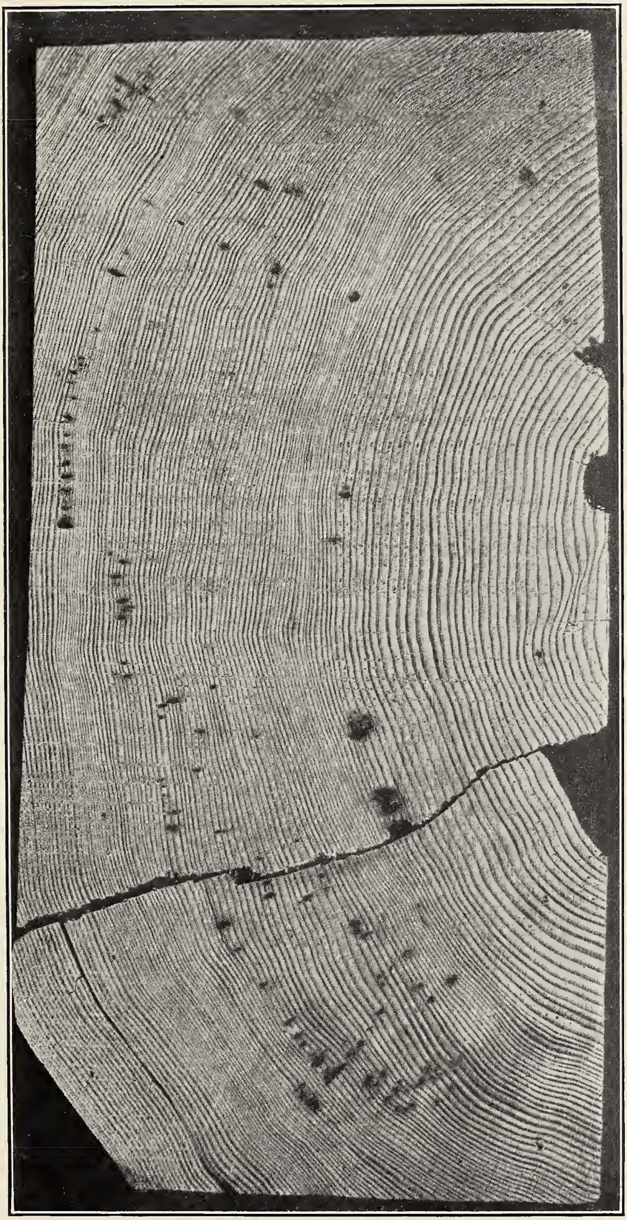
RELATION BETWEEN STRENGTH VALUES.

In figure 2 the strength values, dry weight, and rate of growth are plotted for individual tests for both green and air-seasoned timbers.

The diagram was made by first plotting the values for modulus of rupture, arranged from the highest to the lowest, beginning with the highest value on the left at the top of the figure. The other values for the same beams were then plotted in the same vertical lines. Points for green beams are joined with broken lines and points for air-seasoned beams with solid lines. The three different grades used for structural timber by the West Coast Lumber Manufacturers' Association are designated by the kind of circles used in plotting the points, as shown in the legend on the diagram.

The fiber stress at elastic limit decreases in an irregular way with the modulus of rupture. The modulus of elasticity varies also with the modulus of rupture, but to a less extent. The modulus of rupture and the fiber stress at elastic limit approach each other more closely in passing from the stronger to the weaker pieces. This fact indicates that defects influence the modulus of rupture more than they do the fiber stress at elastic limit.

Figure 3 was made by first plotting the values for modulus of rupture of the stringers from the highest to the lowest, as in figure 2. Values representing other properties of the stringers and the strength properties of the small pieces cut from them were also plotted. The points in any one vertical line represent values for a single beam or average values of pieces cut from that beam. Results for both green and seasoned material are shown in this figure. Values for the modulus of rupture of small pieces shown at the top of the figure represent the bending strength of the wood free from all defects. Comparing the modulus of rupture of the stringers and of the small



ROT SPOTS IN A SECTION CUT FROM A WESTERN HEMLOCK BRIDGE STRINGER.

A SPIRAL GRAIN FAILURE IN AN 8" BY 16" BY 16' BRIDGE STRINGER.

METHOD OF AIR SEASONING TEST TIMBERS.

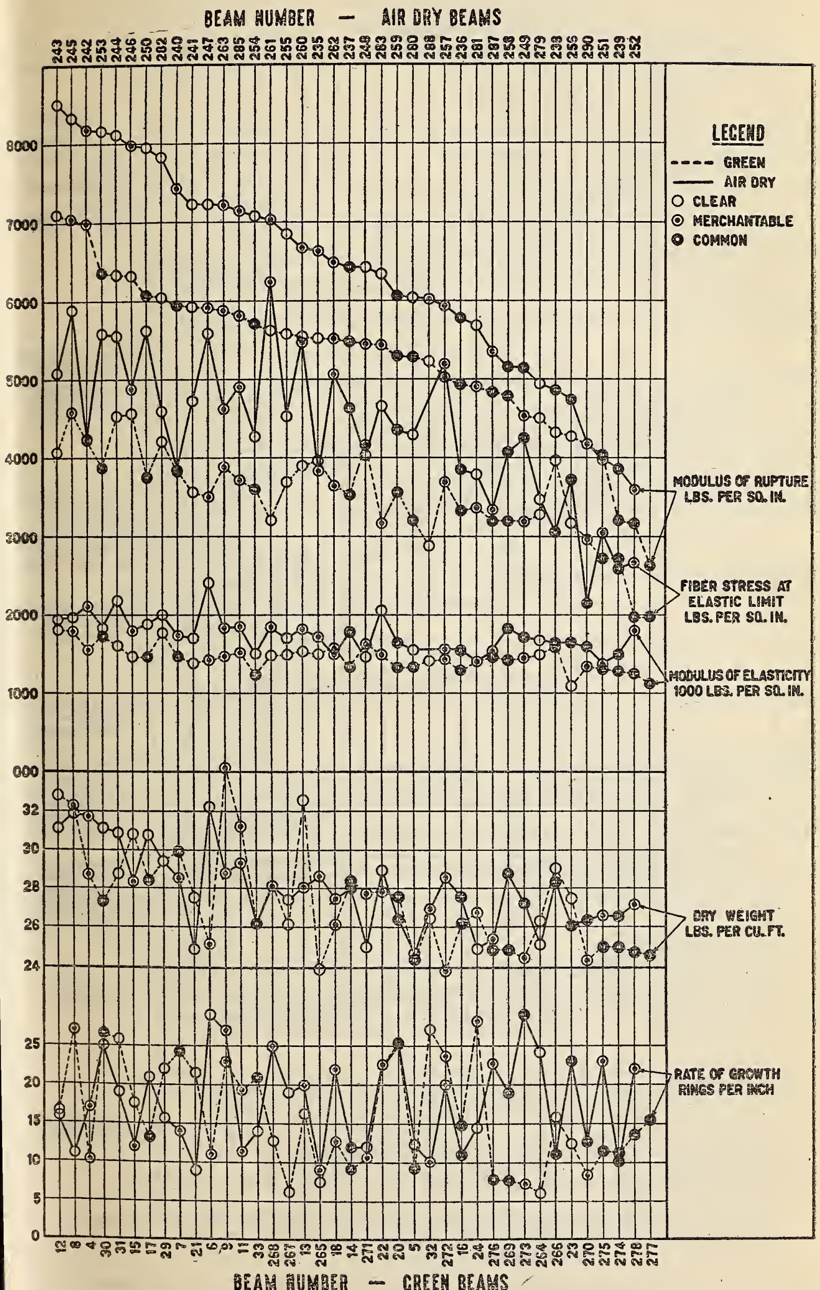


FIG. 2.—Results of individual tests on both green and air-seasoned western hemlock bridge stringers plotted to show relation between modulus of rupture and other test values.

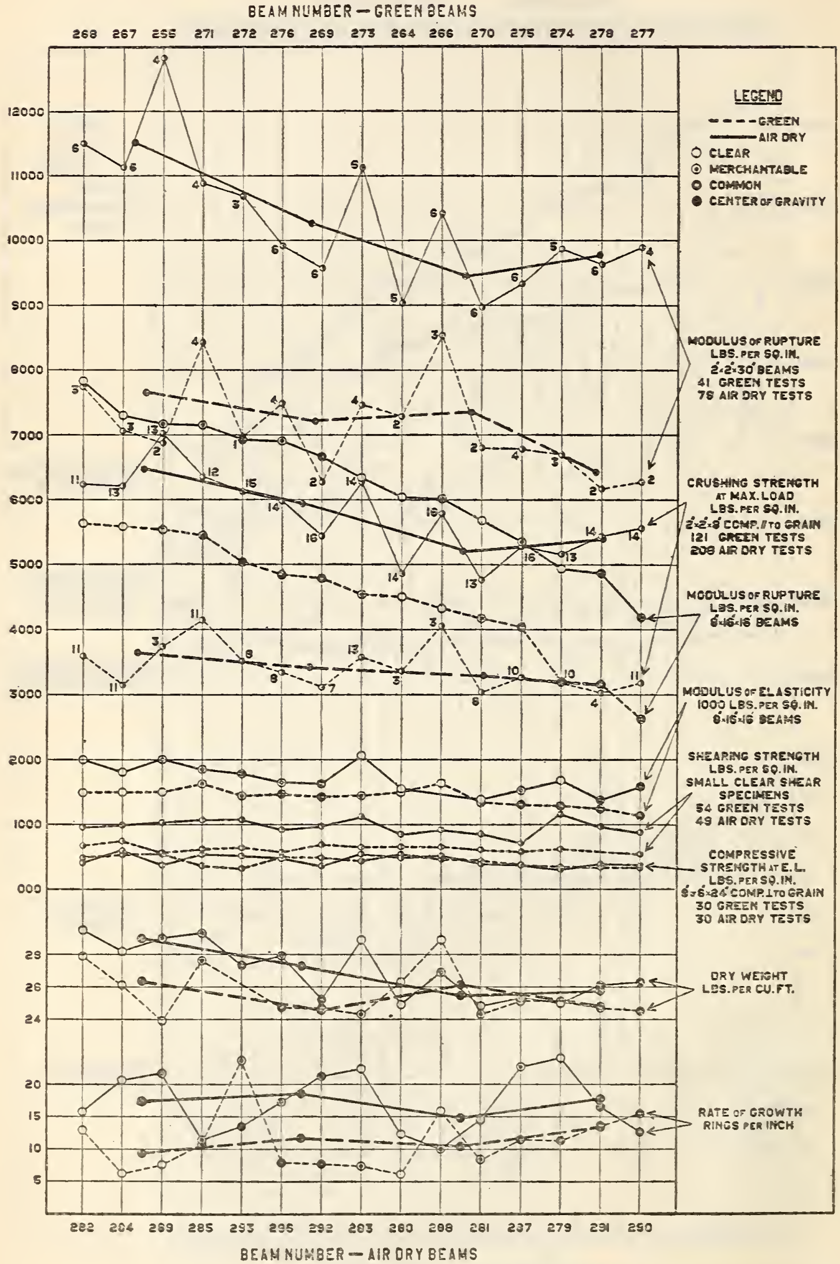


FIG. 3.—Results of individual tests on both green and air-seasoned western hemlock bridge stringers and on small pieces cut from them plotted to show relation between modulus of rupture of stringers and other test values.

pieces shows that as the stringers decrease in strength the small pieces cut from them also decrease, although not in the same degree. This indicates that the greater range of strength in the stringers is due to other things than the quality of the clear wood—that is, to defects such as knots, shakes, and checks. The crushing strength of small pieces also decreases as the modulus of rupture of the stringers becomes less, just as in the case of the small, clear beams. Values for modulus of elasticity in both green and seasoned stringers decreases slightly as the weaker material is encountered. The modulus of elasticity is slightly greater for air-seasoned than for green timber. Values for shearing strength and compressive strength perpendicular to grain show little tendency to change as the modulus of rupture of the large beams decreases.

Table 4 compares the longitudinal shear developed in large timbers and the maximum shearing stress in small specimens. In this summary the results of tests on stringers failing in longitudianl shear only were used. The shearing strength developed in the stringers was but 42 per cent as great as the average shearing strength in small, clear blocks.

TABLE 4.—*Comparison of horizontal shear developed in 8 by 16 inch by 16 foot green and seasoned western hemlock stringers to the shearing strength of small, clear blocks.*

Seasoning condition.	Bending tests.						Shear parallel to grain.		
	Number of tests.	Rings per inch.	Moisture per cent.	Weight per cubic foot. As tested.	Weight per cubic foot. Oven-dry.	Maximum horizontal shear per square inch.	Number of tests.	Maximum shearing strength per square inch.	Ratio large to small.
Green:				*Pounds.*	*Pounds.*	*Pounds.*		*Pounds.*	
Maximum	1	28.1	59.0	43.6	32.8	366	1	894	
Average	13	19.3	34.3	37.3	27.8	265	54	630	0.42
Minimum	1	7.3	25.8	33.9	24.3	204	1	453	
Air-seasoned:									
Maximum	1	29.0	19.5	37.9	32.1	540	1	1,466	
Average	32	18.0	[1] 17.9	32.7	[1] 27.7	390	131	924	.42
Minimum	1	9.0	16.2	29.1	24.8	228	1	454	

[1] Based on 31 tests.

RELATION BETWEEN MECHANICAL PROPERTIES AND PHYSICAL CHARACTERISTICS.

The wide range in the strength of western hemlock timber suggests a study of the relation of defects, rate of growth, weight, and proportion of summerwood to the mechanical properties.

DEFECTS.[1]

It is almost impossible to secure structural timbers in large sizes free from weakening defects. To use such timbers to the best advan-

[1] Defects in timbers are more fully discussed in Forest Service Bulletin 108, "Tests of Structural Timbers," by McGarvey Cline and A. L. Heim.

tage it is necessary to know the influence of these defects upon the strength properties of structural material. Five classes of defects are common in western hemlock: (1) Knots, (2) rot, (3) shakes and checks,[1] (4) cross and spiral grain, (5) sap.

KNOTS.

Knots are classified according to their size and condition. Pin knots are not over one-half inch in diameter; small knots vary from one-half inch to 1½ inches in diameter; large knots are over 1½ inches in diameter. Such terms as sound, loose, rotten, and incased (surrounded entirely or in part by bark or pitch) describe definite classes of knots.

The effect of knots upon the properties of wood has been studied by the Forest Service for several of the most important species found in the United States. There are general relations between knots and the mechanical properties which may be applied to all species. Each species, however, presents special problems of its own.

In western hemlock knots are weakening factors in beams and in timbers subject to compression parallel to grain. Sound knots do not weaken the wood when loaded in compression perpendicular to the grain. Knots which occur near the ends of a beam do not weaken it. A small knot in the central portion near the upper or lower sides which causes a marked disturbance in the grain is more serious than a large knot similarly located which does not interrupt the grain materially. Sound knots which occur in the central portion one-fourth the height of the beam from either edge are not serious defects. Knots on the bottom side of a beam in the central portion are considerably more serious than corresponding knots on the upper side.

Tables 5 and 6 show the effect of knots upon the strength of short columns. From these tables it may be seen that pin knots do not seriously weaken the columns in compression parallel to grain, while large knots reduce the strength in proportion to their size.

[1] For information on black check see Bureau of Entomology Circular No. 61, "Black Check in Western Hemlock."

TABLE 5.—*Effect of knots on strength in compression parallel to grain in green western hemlock.*

[6 by 6 by 24 inch specimens.]

Kind of knots.	Number of tests.	Rings per inch.	Moisture, per cent.	Weight per cubic foot. As tested.	Weight per cubic foot. Oven-dry.	Compressive strength at elastic limit per square inch.	Crushing strength at maximum load per square inch.	Modulus of elasticity per square inch.
None:				*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*1,000 lbs.*
Maximum	1	28.1	100.7	59.1	33.8	3,835	4,060	2,990
Average	46	15.7	48.5	41.2	27.7	3,018	3,507	1,676
Minimum	1	6.0	30.0	31.0	23.8	1,950	2,905	900
Pin knots (sound knots 0.5 inch or less in diameter):								
Maximum	1	22.6	61.4	46.2	29.8	3,610	3,630	1,957
Average	12	12.5	48.4	38.1	25.6	2,880	3,396	1,670
Minimum	1	7.7	30.2	33.0	22.8	2,630	3,190	1,418
Standard knots (sound knots between 0.5 and 1.5 inches in diameter):								
Maximum	1	26.9	55.9	44.0	28.9	3,280	3,540	1,860
Average	11	15.7	42.0	36.6	25.8	2,838	3,197	1,624
Minimum	1	8.2	30.4	33.0	23.8	2,350	2,775	1,363
Large knots (sound knots larger than 1.5 inches in diameter):								
Maximum	1	26.2	61.6	46.3	29.1	3,150	3,405	1,688
Average	13	14.6	42.0	37.9	26.8	2,590	2,901	1,364
Minimum	1	10.0	29.6	34.4	23.8	1,945	2,300	955
Ratios:								
Clear wood					1.00	1.00	1.00	1.00
Pin knots					.92	.95	.97	1.00
Standard knots					.93	.94	.91	.97
Large knots					.97	.86	.83	.81

TABLE 6.—*Effect of knots on strength in compression parallel to grain in air-seasoned western hemlock.*

[6 by 6 by 24 inch specimens.]

Kind of knots.	Number of tests.	Rings per inch.	Moisture, per cent.	Weight per cubic foot. As tested.	Weight per cubic foot. Oven-dry.	Compressive strength at elastic limit per square inch.	Crushing strength at maximum load per square inch.	Modulus of elasticity per square inch.
None:				*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*1,000 lbs.*
Maximum	1	36.0	20.7	37.8	31.7	6,290	7,330	3,279
Average	64	18.6	18.4	32.9	27.8	[1] 5,176	5,952	[1] 2,109
Minimum	1	8.0	16.5	28.0	23.8	3,990	4,440	1,176
Pin knots (sound knots 0.5 inch or less in diameter):								
Maximum	1	26.5	19.5	36.3	30.3	5,260	6,870	1,992
Average	8	18.2	18.6	33.3	28.1	[2] 4,523	6,051	[2] 1,756
Minimum	1	11.0	16.6	28.8	24.4	3,620	5,120	1,585
Standard knots (sound knots between 0.5 and 1.5 inches in diameter):								
Maximum	1	32.5	19.7	39.3	32.9	6,330	6,580	3,131
Average	25	18.1	18.8	34.0	28.6	[3] 4,556	5,516	[3] 2,217
Minimum	1	8.0	17.4	27.9	23.5	3,360	4,110	1,442
Large knots (sound knots larger than 1.5 inches in diameter):								
Maximum	1	26.0	20.0	38.8	32.5	4,860	6,250	2,691
Average	5	14.7	19.3	35.9	30.1	4,248	5,150	[4] 2,215
Minimum	1	9.0	18.5	35.1	29.2	2,980	3,180	1,798
Ratios:								
Clear wood					1.00	1.00	1.00	1.00
Pin knots					1.01	.87	1.02	.83
Standard knots					1.03	.88	.93	1.05
Large knots					1.08	.82	.87	1.05

[1] Based on 32 tests. [2] Based on 3 tests. [3] Based on 24 tests. [4] Based on 4 tests.

Loose and rotten knots in western hemlock are accompanied by an element of uncertainty as to their effect on strength and durability, and should be admitted cautiously, if at all. A distinction, however, should be made between rotten knots and the soft, black knots so characteristic of western hemlock. These soft, black knots are in no sense decayed wood, and are usually accompanied by a more or less pitchy formation, which tends to prevent decay where they occur. Black knots do not appreciably weaken the timber and should not be considered serious defects, so far as strength is concerned, as long as they are small and do not occur in clusters or cause marked disturbance in the grain.

ROT.

Western hemlock is subject to dry-rot, which is one of its worst defects, and one which is very objectionable from the standpoint of both strength and durability. In some instances rot spots occur throughout a timber, making it wholly unfit for structural purposes. These spots are not always easy to detect.

Plate IV shows spots of rot which were found in one of the timbers tested. From this photograph the difficulty of detecting dry-rot will be better understood; the spots shown are entirely within the beam and are visible only on the end grain.

SHAKES AND CHECKS.

Although the cause of shakes is not definitely known, they are usually ascribed to wind pressure; in some cases they may be caused also by freezing. They are often difficult to detect.

Checks are usually the result of seasoning. They are not often encountered in commercial grading, which is usually done while the timbers are green.

Checks which form during the process of air seasoning usually reduce the area of the neutral plane,[1] and thus increase the chance of failure by longitudinal shear. In beams of small depth, as compared to their span, the tendency to fail under test by shearing lengthwise is slight; but in 8 by 16 inch beams tested over a 15-foot span the ratio of depth to span makes failure by shearing very likely if the neutral plane is weakened. Table 7 shows the number of green and seasoned beams that failed by longitudinal shear. The seasoned pieces exhibited greater strength than the green material, but were unquestionably weakened by the checks which formed during the seasoning period.

[1] Plane between the upper and lower halves when beam is horizontal.

TABLE 7.—*Number of western hemlock bridge stringers failing in shear (15-foot span).*

Number of pieces tested.	Condition of seasoning.	Cross section.	Number failing in shear.
		Inches.	
39	Green	8 x 16	13
44	Air seasoned	8 x 16	32

However, excessive checking due to improper seasoning may, in some cases, more than offset the increased strength gained in drying.

CROSS AND SPIRAL GRAIN.

A very common defect found in timbers is cross-grain. It is caused by improper sawing or by knots. Cross-grain in the vicinity of knots is local, and may or may not be serious, depending upon its extent and position. Spiral grain is another defect. It is easily detected in sawed timbers after slight seasoning checks have developed. In sticks with spiral grain these checks will appear across the apparent grain (formed by the annual rings). Failure in timbers with spiral grain usually follows these season checks. It is sometimes possible to detect spiral grain by the position of the pith rays, although in western hemlock these are often difficult to see without the aid of a glass. (See Pl. III.) In normal trees the pith rays lie in vertical planes, while in trees with spiral grain their position is more or less inclined. Plate V shows bottom and side views of the central portion of an 8 inch by 16 inch by 16 foot beam in which the failure was due to spiral grain.

Cross or spiral grain may be a sufficient cause for putting timber in the lowest grade.

SAPWOOD.

Hemlock contains only a slight amount of sapwood, and, as structural timbers are usually cut from the central portions of the logs, sapwood rarely occurs in such material.

Sapwood is practically as strong as heartwood, but is objectionable in structural timbers because it does not resist decay.

RATE OF GROWTH.

The rate of growth was determined for all specimens tested, in order that any relation between this factor and the mechanical and physical properties might be ascertained. Various opinions have been held in regard to the effect of rate of growth upon the strength of structural timbers. In certain specifications timbers of very slow or very rapid growth are excluded. Other specifications do not mention rate of growth.

STRINGERS.

In figures 2 and 3 the rate of growth curves show but little variation from the horizontal as the stringers decrease in strength, indicating that in market material the rate of growth is of little value in judging the strength. In such material any possible increase in strength due to a certain rate of growth is liable to be offset by the weakening effect of defects.

SMALL STICKS.

In studying the effect of rate of growth on the strength of small specimens, only clear, straight-grained, green material was used. The relation between rate of growth and the various strength values for such specimens is shown in figure 4. The diagram indicates that, except for shear, in the strongest material the rate of growth is between 12 and 20 rings per inch.

WEIGHT.

The western hemlock test material varied in weight from 19 to 35 pounds per cubic foot for dry wood. Former tests made by the Forest Service have shown that the relation which exists between weight and strength is very definite and that the dry weight may be depended upon almost invariably in judging the strength of any clear piece of wood.

STRINGERS.

Figure 2 shows that the dry weight in stringers decreases rather uniformly with a decrease in strength. There is, however, some variation in the individual tests, and some comparatively heavy stringers showed low strength values. This is because in such timbers the weakening effect of defects more than offsets the increased strength due to the greater weight.

SMALL STICKS.

The relation between weight and strength values for small sticks without defects is shown in figure 5. The strength values, except those for the shearing tests, gradually increase with the weight of the material.

SUMMERWOOD.

Since the summerwood in the annual rings is heavier and stronger than the springwood, it is apparent that sticks with the same number of rings per inch but with different proportions of summerwood will vary in strength; therefore, weight is a more certain criterion of strength than rate of growth. However, in many species tested by the Forest Service the largest proportion of summerwood is associated with certain rates of growth, the limits differing in different species.

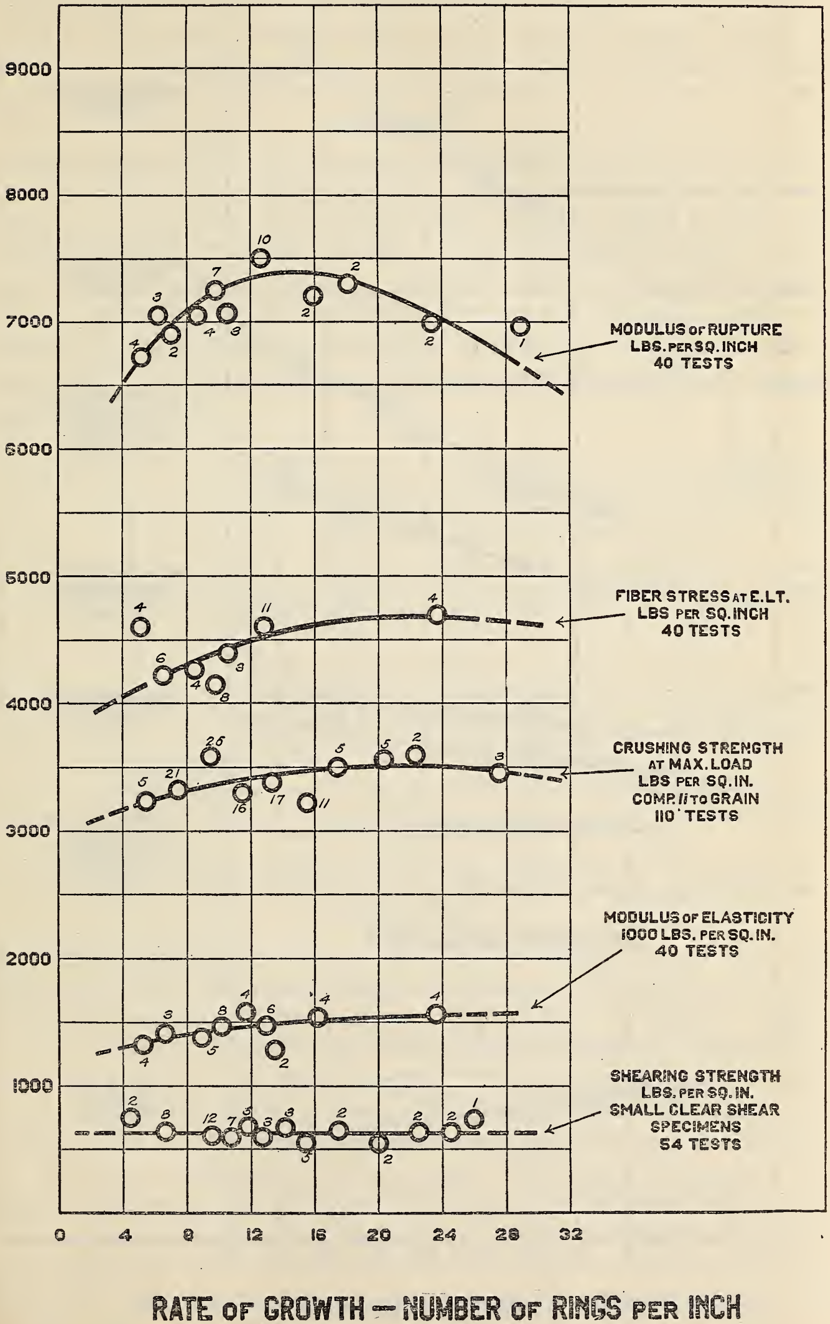


FIG. 4.—Relation between strength and rate of growth as shown by results of tests of small, clear specimens of green western hemlock.

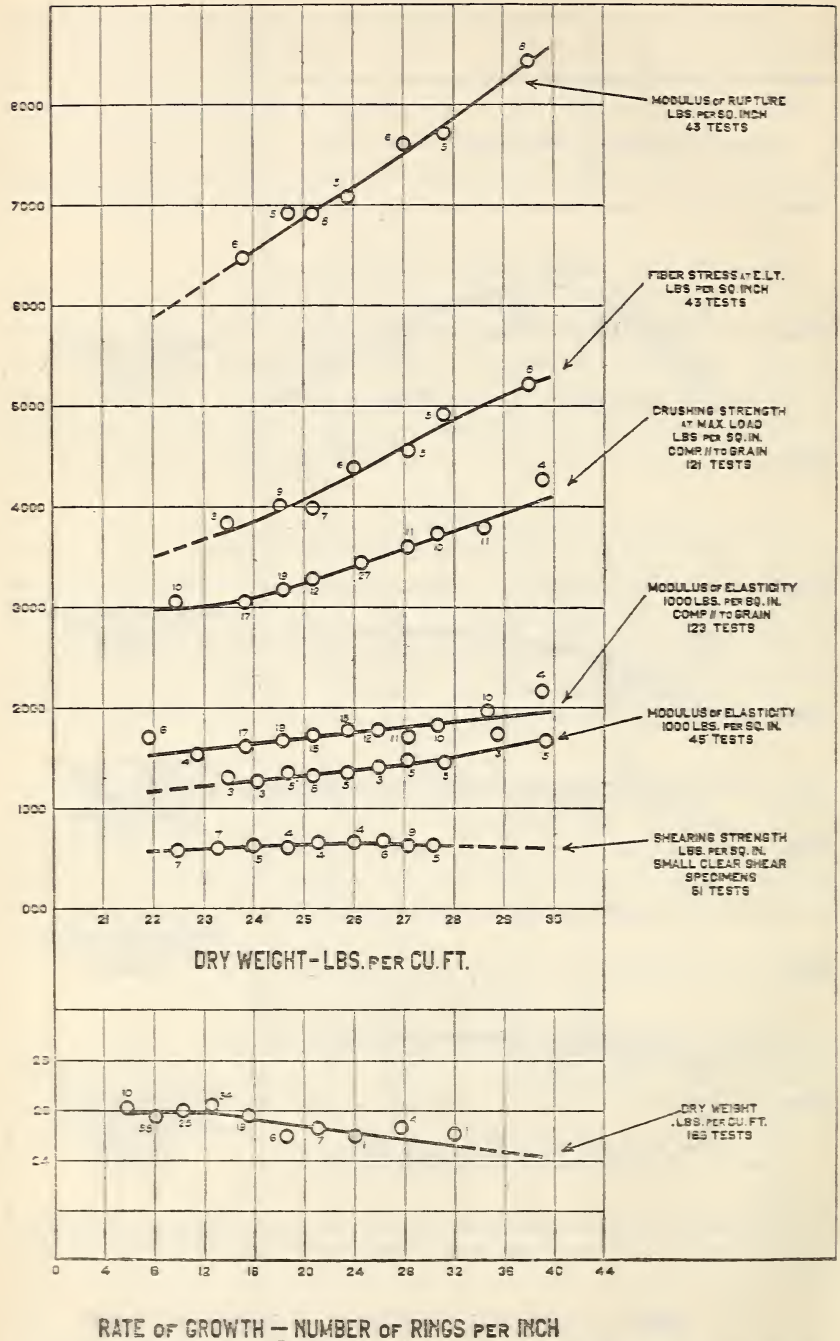


FIG. 5.—Relation of strength values and rate of growth to dry weight. Small, clear sticks of green western hemlock.

Plate I shows that in western hemlock the summerwood, or the dense portion of the annual ring, gradually merges into the springwood or the more porous portion. This gradual change makes it impossible to determine accurately the proportion of summerwood in the test material.

SEASONING.

Wood when freshly cut contains considerable moisture, the amount varying widely for different species. Green western hemlock contains, as a rule, from 40 to 60 per cent moisture, while Douglas fir usually has from 30 to 40 per cent. Large timbers will season much more slowly than small pieces. Under conditions obtaining about Seattle, hemlock bridge stringers will lose a considerable portion of their moisture and reach a condition of constant weight in about a year, while small sticks 2 by 2 by 30 inches will thoroughly air season in 60 days.

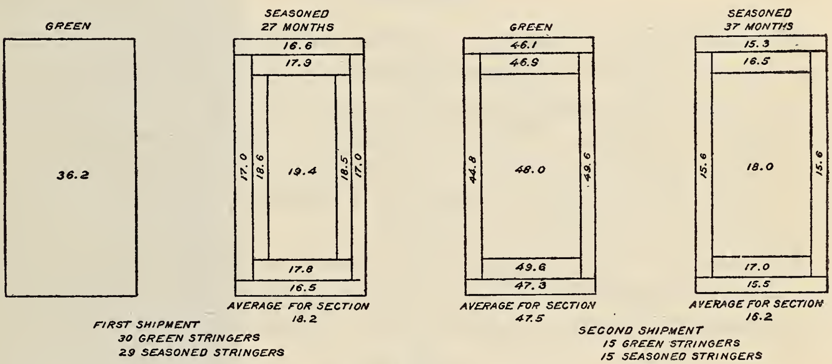


Fig. 6.—Summary of moisture determination made upon green and seasoned bridge stringers of western hemlock.

DISTRIBUTION OF MOISTURE AND RATE OF SEASONING IN BRIDGE STRINGERS.

Moisture determinations, as described on page 8, were made on both green and seasoned bridge stringers. The results of these determinations are given in figure 6 and show a slightly higher moisture content in the center of the timbers than near the surface, for both green and seasoned pieces. The average moisture content of the green stringers in the first shipment (36.2 per cent) was considerably less than the moisture content of the green stringers in the second shipment (47.5 per cent). This fact was due to the partial seasoning that occurred before the first shipment was tested The amount of moisture in the seasoned stringers of both shipments was about the same (18.2 and 16.2 per cent), although the first shipment was seasoned for a considerably longer time than the second. Figure 7 indicates that but little further loss in weight is to be expected in stringers after the first year's seasoning.

The timbers to be seasoned were open piled under cover (Pl. VI), and some were weighed at intervals to determine the rate at which they were losing weight. The results of these weighings are plotted in figure 7. One shipment of timbers was placed in the seasoning shed early in July, 1906, and the other shipment was stacked in the same shed one year later. The diagram shows the loss in weight in pounds which occurred at different periods during seasoning. The first shipment of stringers lost about 76 pounds each, or 15 per cent of their weight in 12 months. At the end of 27 months the average loss was 86 pounds per stringer, or 17 per cent of the original weight.

The second shipment of stringers lost an average of 60 pounds each, or 14 per cent, in 12 months. At the end of 37 months the average loss was 80 pounds, or 18 per cent of the original weight.

SHRINKAGE.

The shrinkage or swelling of wood is caused by a decrease or increase of moisture. If green material is used for building purposes, it may season after being put in place and cause trouble by shrinking, warping, or checking. While the amount of moisture in material to be used for structural purposes is of less importance than in material for inside finish, furniture stock, and similar purposes, it should, nevertheless, be carefully considered.

Measurements and weighings were taken on both large and small specimens of western hemlock, in order to determine the change in dimensions that may be expected with various moisture contents.

STRINGERS.

Figure 7 shows the variation in the cross section of the stringers that occurred at different periods of seasoning. For the first few months the shrinkage was very noticeable. As the wet season approached both the loss in weight and the amount of shrinkage grew less, and finally, during May, a slight gain in both weight and cross section took place, due to the absorption of moisture. During the following summer the timbers again gradually lost moisture, and in the fall and winter made another gain in weight. There was a decided gain in cross section during the second gain in weight, due to the fact that much of the moisture absorbed was in the outer portion of the timbers, thus causing a large amount of swelling relative to the gain in weight. The average weight of the stringers in March, 1908, was approximately 445 pounds (first shipment), and the corresponding area of the cross section was 112.8 square inches. The stringers had the same cross section in September, 1906, when the average weight was 478 pounds. The second shipment placed in the seasoning shed in July, 1907, shows the same general results as the first.

FIG. 7.—RATE OF SEASONING AND RESULTING AMOUNT OF SHRINKAGE IN BRIDGE STRINGERS.

SMALL STICKS.

Tests were made upon small, selected specimens in order to determine the relation between moisture content and shrinkage, as well as the total amount of shrinkage which occurs in western hemlock in passing from a green to an oven-dry condition. The specimens were cut 3 by 3 inches in cross section by 12 inches long, and were measured from time to time during the process of seasoning.

Figure 8 shows the relation between moisture content and the cross-sectional area. Practically no shrinkage occurred in the specimens while passing from the original green condition to one of about 31 per cent moisture. When dried below 31 per cent moisture the pieces began to shrink and continued to do so until all the moisture was driven out.

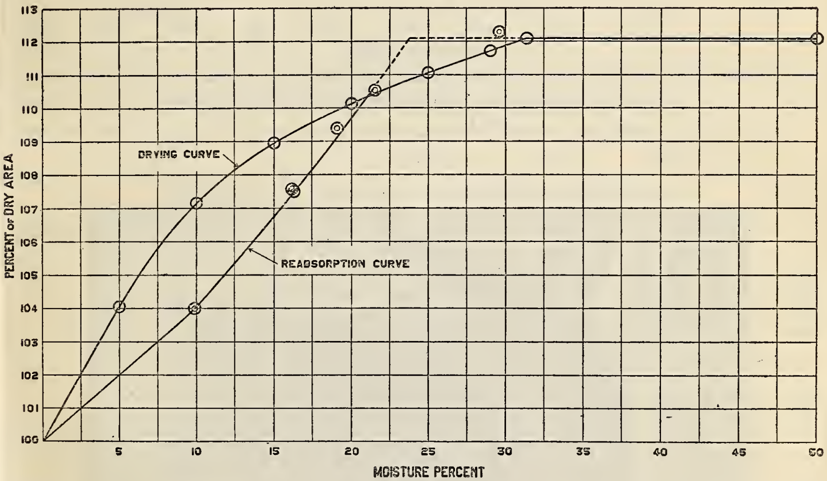


FIG. 8.—Relation between the moisture content and the cross section of small, clear pieces of western hemlock.

An attempt was made to dry the pieces uniformly, but sectional moisture determinations made from time to time showed that the drying in the interior of the pieces was much slower than near the surface. Similar moisture determinations were made during the absorption tests, and up to approximately 10 per cent the moisture was uniformly distributed. Above 10 per cent, however, the surface portions showed a higher moisture content than the interior.

It will be noted that the drying and absorption curves (fig. 8) are quite different. This is because the distribution of moisture in the various specimens was different for the two tests. The effect of this difference in the distribution of moisture is shown also in figure 9, which is plotted from measurements of the cross section determined in two ways:

(1) By using the average dimensions *aa* and *cc*, and *dd* and *ff* (fig. 10); (2) by using the dimensions *bb* and *ee* (fig. 10).

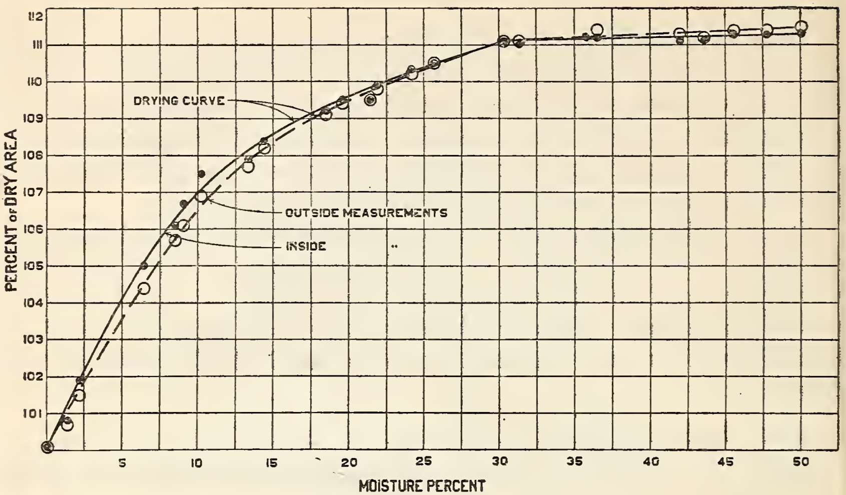


FIG. 9.—Relation between the moisture content and the cross section of small, clear pieces of western hemlock. Measurements taken in two ways.

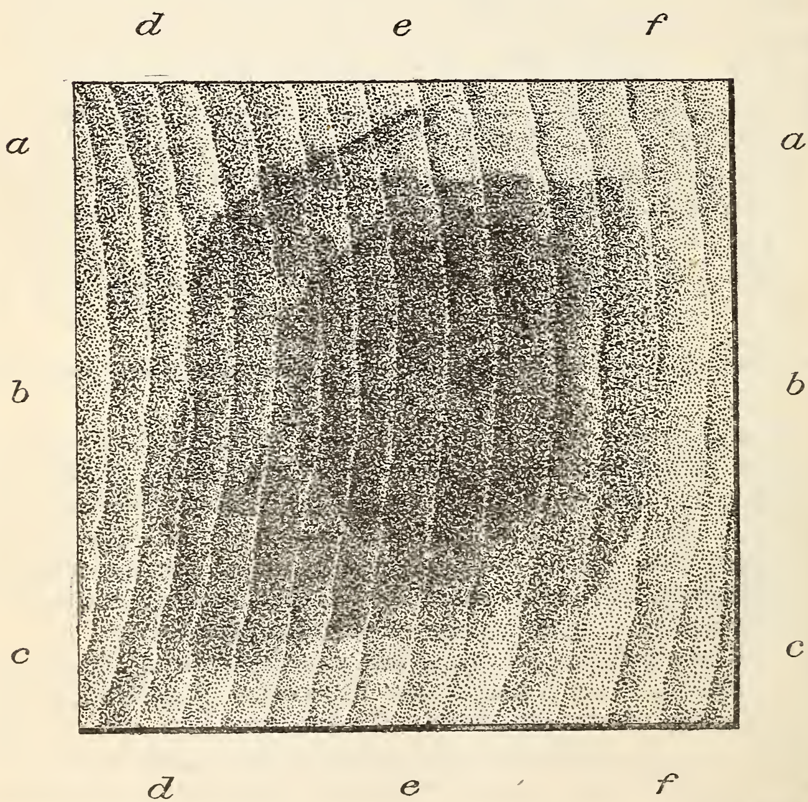


FIG. 10.—Positions on sticks where shrinkage and swelling measurements were taken.

From figure 10 it is evident that the dimension *aa* will be more affected by external drying than dimension *bb*. The result (fig. 9) shows that the shrinkage was uniformly greater by the outside measurements than by the inside measurements at all stages of seasoning.

Western hemlock, in passing from a thoroughly green to a bone-dry condition, shrinks 5, 8.4, and 0.08 per cent, respectively, in a radial, tangential, and longitudinal direction; the change of volume is 13.8 per cent. These figures are based on the volume of thoroughly dry wood.

STRENGTH AS AFFECTED BY SEASONING.

A full discussion of the effect of moisture upon the mechanical properties of wood in the form of small specimens is contained in Bulletin 70[1] of the Forest Service. During the progress of the tests on western hemlock similar data were secured for both large and small specimens.

Table 8 gives the results secured from tests on bridge stringers, summarized to show the effect of seasoning on the fiber stress at elastic limit, modulus of rupture, and modulus of elasticity for clear, merchantable, and common grades, and for all grades combined.

TABLE 8.—*Comparison of results of tests of 8 by 16 inches by 16 feet green and air-seasoned western hemlock bridge stringers.*

[Graded in accordance with the export rules of the Pacific Coast Lumber Manufacturers' Association.]

Grade.	Seasoning condition.	Number of tests.	Rings per inch.	Moisture.	Summerwood.	Weight per cubic foot.		Fiber stress at elastic limit.	Modulus of rupture.	Modulus of elasticity.
						As tested.	Oven dry.			
				P. ct.	P. ct.	Lbs.	Lbs.	Ratio.	Ratio.	Ratio.
Clear	Green	12	15.5	41.4	43	40.0	28.3	1.00	1.00	1.00
	Seasoned	16	17.8	17.8	46	33.3	28.3	1.28	1.29	1.22
Merchantable	Green	11	16.0	47.6	39	41.1	27.8	1.00	1.00	1.00
	Seasoned	16	18.4	17.7	42	33.1	28.2	1.21	1.15	1.15
Common	Green	16	15.4	39.9	33	36.7	26.3	1.00	1.00	1.00
	Seasoned	12	[1] 17.0	17.6	[2] 43	31.7	27.0	1.18	1.10	1.20
All grades	Green	39	15.6	42.5	38	39.0	27.3	1.00	1.00	1.00
	Seasoned	44	[3] 17.8	17.7	[4] 44	32.8	27.8	1.25	1.21	1.20

[1] Based on 9 tests. [2] Based on 8 tests. [3] Based on 41 tests. [4] Based on 30 tests.

The modulus of rupture is affected more than either of the other factors mentioned. In the clear grade an increase of 29 per cent in the modulus of rupture was secured by air seasoning. In the grades merchantable and common the increase was 15.5 and 10 per cent, respectively. An increase in strength due to seasoning is also shown for the fiber stress at elastic limit, but the variation in the different grades is slightly less than for the modulus of rupture.

The modulus of elasticity is affected by air seasoning to about the same extent in each of the different grades. The air-seasoned material in the clear, merchantable, and common grades exhibited a modulus of elasticity of 21.5, 14.7, and 19.7 per cent, respectively, greater than was shown for the green material.

[1] "Effect of Moisture upon the Strength and Stiffness of Wood," by H. D. Tiemann.

Figure 11 shows that the effect of moisture upon the strength of small, clear specimens is very much more marked than in bridge stringers. The table given in connection with the diagram shows the relative gain in the maximum crushing strength, modulus of rupture, and modulus of elasticity corresponding to the various moisture conditions. The maximum crushing strength was 3.45 times as great for thoroughly dry wood as for green pieces. Similar gains of 2.40 and 1.42 are shown for modulus of rupture and modulus of elasticity, respectively. The large increase in strength is due to the fact that fairly uniform seasoning can be effected in small material with practically no checking. Bridge stringers do not season uniformly, but develop many checks. These checks, as previously stated, cause timbers to fail by horizontal shear, and are the reason why the net gain in strength in seasoned timbers is so slight.

The curves shown in figure 11 indicate no increase in the various properties until seasoning has reduced the moisture content to about 31 per cent. Further seasoning then greatly increases these properties. The point at which the increase begins is termed the "fiber-saturation point."[1]

SPECIFICATIONS AND GRADING RULES.

The outside portions of logs are generally cut into lumber and the central part used for structural forms. As the central part usually contains most of the defects, structural material is seldom clear. In order to use it to the best advantage it is necessary to have rules by which timbers containing defects can be divided into groups of relatively the same strength and stiffness.

The points for consideration in grading timber, aside from general requirements as to size, soundness, sawing, and freeness from rot, are (1) knots (position, size, and number); (2) checks and shakes; (3) grain (rapid or slow growth, straightness); (4) amount of sapwood.

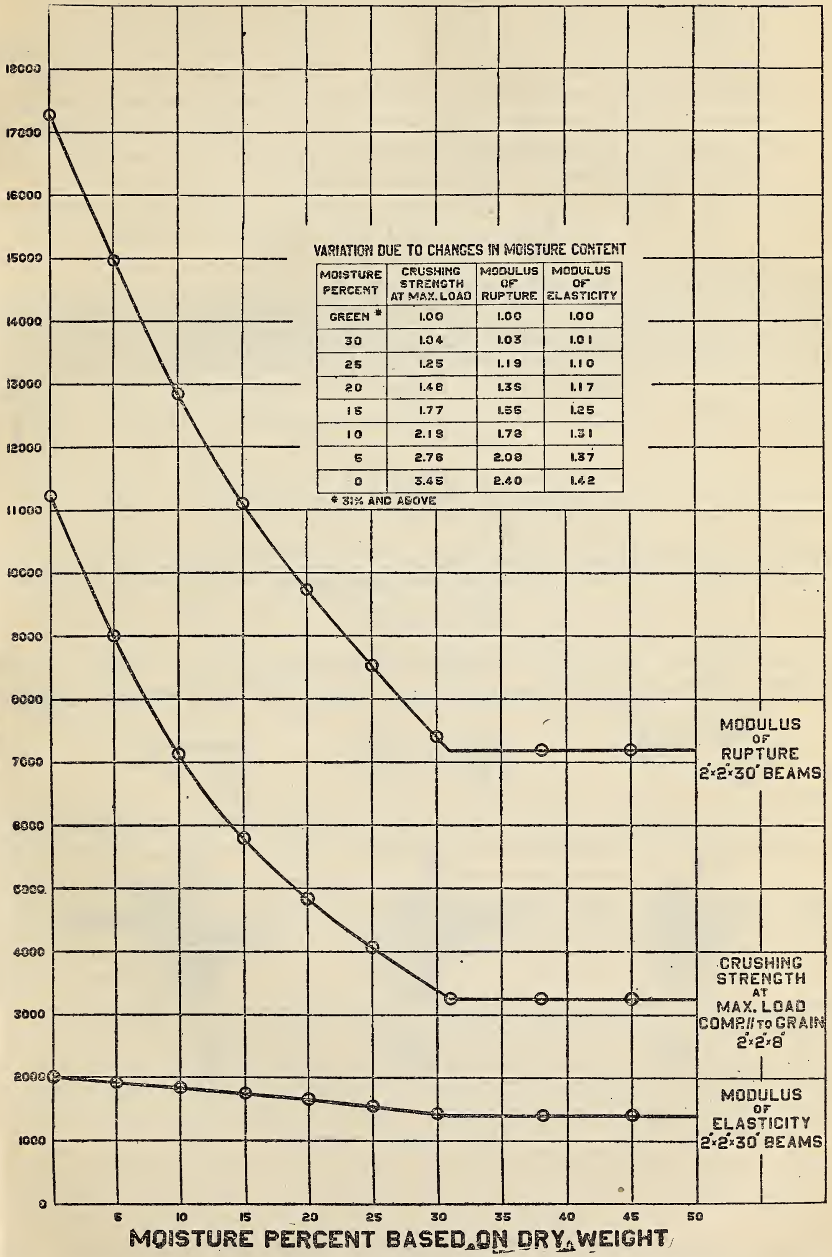
Present grading rules are either very general and loose or else so rigidly drawn as to exclude many timbers of high strength. The following are examples of grading specifications, some of which cover only one grade, while others have several grades:

SPECIFICATION A.

Specification A is used by one of the leading transcontinental railway systems.

> All timber must be of the best description of the kind required. It must be sawed square and to proper dimensions. It must be free from all loose, large, or unsound knots, sap, sun cracks, shakes, wanes, or other imperfections or defects which would impair its strength or durability.

[1] Forest Service Bulletin 70.



VARIATION DUE TO CHANGES IN MOISTURE CONTENT

MOISTURE PERCENT	CRUSHING STRENGTH AT MAX. LOAD	MODULUS OF RUPTURE	MODULUS OF ELASTICITY
GREEN *	1.00	1.00	1.00
30	1.04	1.03	1.01
25	1.25	1.19	1.10
20	1.48	1.36	1.17
15	1.77	1.56	1.25
10	2.13	1.78	1.31
5	2.76	2.08	1.37
0	3.45	2.40	1.42

* 31% AND ABOVE

FIG. 11.—Effect of varying degrees of moisture upon the strength of small, clear specimens of western hemlock.

SPECIFICATION B.

Specification B is used by the Isthmian Canal Commission:

Stringers.—Douglas fir shall show not less than 85 per cent heart on any face and not less than 70 per cent on any edge; it shall show not less than an average of 12 annual rings to the inch. Sound knots less than 3 inches in diameter shall be permitted in the vertical faces of the stringer at points not less than one-fourth the depth from the edge of the piece.

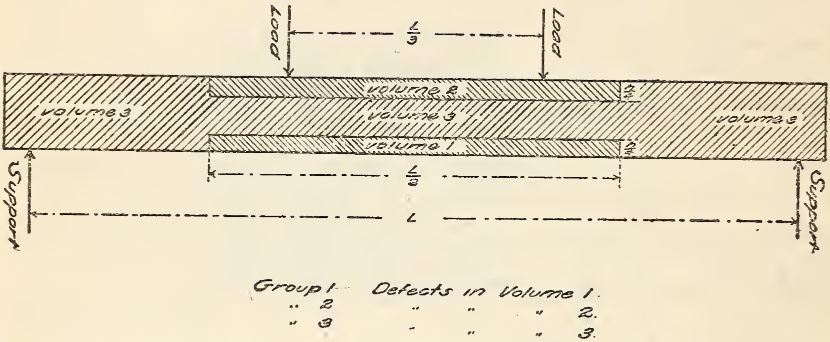


FIG. 12.—Method of dividing beams into three volumes so that they can be grouped according to location of knots.

SPECIFICATION C.

Specification C is the standard adopted by the Pacific Coast Lumber Manufacturers' Association (now the West Coast Lumber

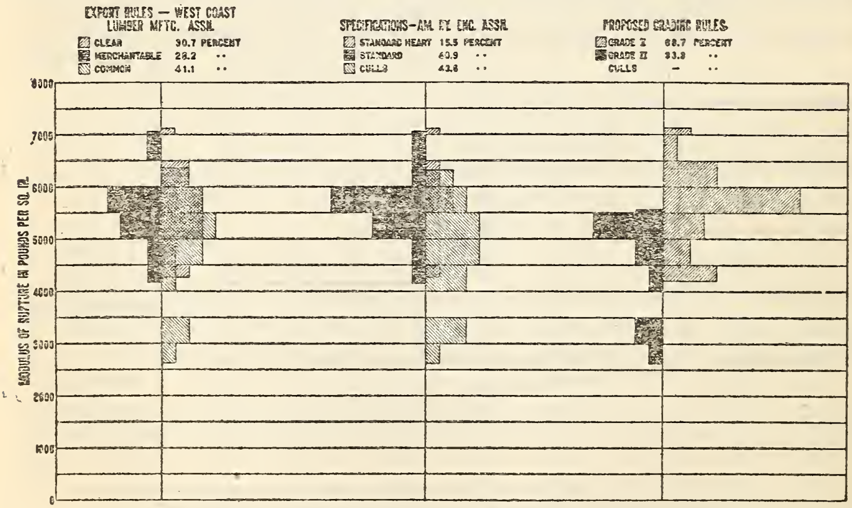


FIG. 13.—Diagram showing range in strength of the various grades in each of three sets of grading rules.

Manufacturers' Association) in 1911. But very slight changes have been made in this set of grading rules since 1899:

Clears.—Shall be sound lumber well sawed, one side and two edges free from knots and other defects impairing its use for the

probable purpose intended. Will allow in dimensions larger than 6 inches by 10 inches pitch pockets when not extending through the piece; light-colored sap on corners not exceeding 3 inches on face and edge, knots 2 inches and less in diameter, according to size of piece, when on one face and one-half of each corresponding edge, leaving one face and upper half of each edge clear.

Selects.—Shall be sound, strong lumber, well sawed. Will allow in sizes over 6 inches by 6 inches, knots not to exceed 2 inches in diameter, varying according to the size of the piece; sap on corner not to exceed 2 inches on both face and edge; pitch pockets not to exceed 6 inches in length. Defects in all cases to be considered in connection with the size of the piece and its general quality.

Merchantable.—This grade shall consist of sound, strong lumber, free from shakes, large, loose, or rotten knots and defects that materially impair its strength, well manufactured, and suitable for good, substantial constructional purposes. Will allow slight variations in sawing, sound knots, pitch pockets, and sap on corners, one-third the width and one-half the thickness or its equivalent. Defects in all cases to be considered in connection with the size of the piece and its general quality. In timber 10 inches by 10 inches and over, sap shall not be considered a defect. Discolorations through exposure to elements, other than black sap, shall not be deemed a defect excluding lumber from this grade, if otherwise conforming to merchantable grade.

Common.—This grade shall consists of lumber having knots, sap, and other defects which exclude it from grading as merchantable, but of a quality suitable for rough kinds of work.

SPECIFICATION D.

Specification D was prepared by the American Society for Testing Materials and, with slight changes, was adopted by the American Railway Engineering Association.

Standard specifications for Douglas fir and western hemlock bridge and trestle timbers. To be applied to single sticks and not to composite members:

Standard heart grade.—Shall include yellow and red Douglas fir and western hemlock. White Douglas fir will not be accepted.

General requirements.—All timber shall be live, sound, straight and close-grained, cut square cornered, full length, not more than one-fourth inch scant in any dimension for rought timber or one-half inch for dressed timber, free from large, loose, or unsound knots, knots in groups, or other defects that will materially impair its strength for the purpose for which it is intended. Subject to inspection before loading.

Stringers.—Shall show not less than 90 per cent heart on each side and edge, measured across the surface anywhere in the length of the piece. Shall be out of wind and free from shakes, splits, or pitch pockets over three-eighths inch wide or 5 inches long. Knots greater than 2 inches in diameter will not be per-

mitted within one-fourth of the depth of the stringer from any corner nor upon the edge of any piece; knots shall in no case exceed 3 inches in diameter.

Standard grade.—Shall include yellow, red, and white Douglas fir and western hemlock.

General requirements.—All timbers shall be sound and cut square cornered, except that timbers 10 inches by 10 inches in size may have a 2-inch wane on one corner or its equivalent on two or more corners. Other sizes may have proportionate defects. Must be free from defects which will impair its utility for temporary work. Knots shall not exceed one-fourth the width of the surface of the piece in which they occur. Subject to inspection before loading.

Stringers.—Shall be out of wind, free from shakes or splits extending over more than one-eighth of the length of the piece, or knots more than 4 inches in diameter. Knots greater than 3 inches in diameter will not be permitted on the edge of any stringer.

SPECIFICATION E.

The rules proposed by the Forest Service are based on observations made during the tests and on a study of the strength data with special reference to physical characteristics. The purpose of the rules is to classify timbers according to their mechanical properties. The following definitions with regard to defects and quality of the wood apply in the proposed rules:[1]

Dense wood.—Wood which is resilient; that is, when struck with a hammer or similar blunt instrument it must give a sharp, clear sound, and the hammer must show a marked tendency to rebound and the wood to recover from the effect of the blow.

Class 1 knots.—Class 1 knots must be solid, firmly attached to the surrounding wood, and cause no marked irregularity in the grain of the timber. Small spike knots will be included in this class.

Class 2 knots.—Class 2 knots must be solid, but are insecurely attached to the surrounding wood or associated with burl or other irregularity in the grain.

Class 3 knots.—Class 3 knots are unsound knots; that is, they are softer than the surrounding wood.

Diameter of knots.—The diameter of a knot on the narrow face of a timber will be its projection on a line perpendicular to the edges of this face. On the wide or vertical face the smallest dimension of a knot is taken as its diameter.

Small knots.—Knots less than 1½ inches in diameter.

Large knots.—Knots 1½ inches or more in diameter.

The following general requirements are considered applicable to western hemlock timbers:

General requirements—Bridge stringers.—All timbers shall be live and sound, cut square cornered, full length, not more

[1] The definitions and proposed rules are reprinted from Forest Service Bulletin 108, "Tests of Structural Timbers," by McGarvey Cline and A. L. Heim. The general requirements here given for western hemlock are not a part of the proposed classification given in Bulletin 108.

than one-fourth inch scant in any dimension for rough timbers, or one-half inch for dressed timbers; free from rotten knots or large knots in groups. Shall show not less than 90 per cent heart on each side and edge measured across the surface anywhere in the length of the piece. Soft black knots shall not be considered rotten knots. Special care shall be given to exclude timbers containing rot spots from grades 1 and 2.

Grade 1 timbers:

a. Must contain only dense wood.
b. Must not have class 2 or class 1 knots in volume 1. (See fig. 12.)
c. Must not have large class 2 knots in volume 2.
d. The aggregate diameter of knots on any face within the center half of the length shall not exceed the width of the face.
e. Must not have shakes or deep checks.
f. Must not have diagonal or spiral grain with a slope greater than 1 inch in 20.

Grade 2 timbers:

a. Must contain only dense wood.
b. Must not have large class 2 knots in volume 1.
c. The aggregate diameter of knots on any face in the center half of the length shall not exceed two times the width of the face.
d. Must not have shakes extending along an annual ring a distance greater than the width of the piece.

DISCUSSION OF GRADING RULES.

By comparing the specifications it is apparent that a wide variation exists in the grading rules now in use. Some of the specifications are very severe and exclude timbers which would better serve for construction purposes than other pieces which are admitted. This seems to be due largely to the fact that too little weight is given to the position of knots and other defects. The results of the tests show very conclusively that the character, size, and position of the defects all bear close relations to the action of timbers under test.

Specification A.

Specification A is a typical example of one in which a great deal is left to the judgment of the inspector. Under this specification many timbers which are suitable for construction purposes may be culled.

Specification B.

Specification B is rigid so far as knots are concerned, and, when applied to western hemlock, the limit on the rate of growth is such as to exclude a great many timbers which are of high structural merit. Figure 2 shows that about 27 per cent of the green stringers

which had a modulus of rupture of over 5,000 pounds had less than 12 rings per inch, and that 36 per cent of the air-seasoned stringers which had a modulus of rupture of over 6,000 pounds had less than 12 rings per inch. Under the specification, therefore, these stringers would be disqualified from use.

SPECIFICATION C.[1]

Specification C has been used on the Pacific coast for years in approximately its present form, and appears to have given fair satisfaction.

Table 9 shows the average values obtained for bridge stringers of green western hemlock graded by this specification. The stringers which graded clear had an average modulus of rupture of 5,527 pounds per square inch. The same values for the merchantable and common grades were 5,616 and 4,903 pounds per square inch, respectively. From these figures it will be seen that the merchantable beams were stronger than the clear beams.

TABLE 9.—*Results of tests of 8 by 16 inches by 16 foot green western hemlock bridge stringers graded in accordance with the export rules of the Pacific Coast Lumber Manufacturers' Association (15-foot span).*

Grade.	Number of tests.	Rings per inch.	Moisture.	Summerwood.	Weight per cubic foot.		Fiber stress at elastic limit per square inch.	Modulus of rupture per square inch.	Modulus of elasticity per square inch.
					As tested.	Oven-dry.			
Clear:			*Per ct.*	*Per ct.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*1,000 lbs.*
Maximum	1	27.2	58.7	67	51.7	32.8	4,570	7,110	1,806
Average	12	15.5	41.4	43	40.0	28.3	3,731	5,527	1,493
Minimum	1	6.1	27.6	32	34.1	26.1	2,875	4,270	1,095
Merchantable:									
Maximum	1	27.0	64.2	55	51.6	34.2	4,580	7,050	1,788
Average	11	16.0	47.6	39	41.1	27.8	3,698	5,616	1,514
Minimum	1	7.3	29.1	25	34.4	23.9	2,950	4,170	1,344
Common:									
Maximum	1	26.5	59.0	43	43.2	29.9	3,880	6,360	1,721
Average	16	15.4	39.9	33	36.7	26.3	3,230	4,903	1,362
Minimum	1	7.7	27.2	25	32.6	24.5	1,970	2,620	1,131
Ratios:									
Clear						1.00	1.00	1.00	1.00
Merchantable						.98	.99	1.02	1.01
Common						.93	.87	.89	1.91

The strictness of this specification with regard to knots makes it unduly severe on western hemlock, which contains many small black knots. These affect the strength but slightly, if at all. The specification throws such material into the lower grades. In judging the efficiency of grading rules it is more important to know the range in strength values in the different grades than the average values. Table 9 shows that the strongest timbers in the common grade are

[1] The grading rules of the Pacific Coast Lumber Manufacturers' Association (now the West Coast Lumber Manufacturers' Association), specification C, were used as a basis of division of the bridge stringers summarized in the various tables in this bulletin unless otherwise noted.

much stronger than the weakest timbers in either of the better grades. The strongest timbers in the first and second grades are of almost equal strength, and this is true also of the weakest pieces. The specification therefore does not grade the timber efficiently.

Specification D.

Specification D is very rigid, and by its use many timbers are excluded from the highest grade which are as strong as those admitted. The clause with regard to defects under "General requirements" leaves almost entirely to the inspector the decision as to what defects impair the strength. Table 10 shows the average values for green western hemlock stringers grouped according to this specification. Two grades of material are specified, "standard heart" and "standard." The group designated as "culls" is included to take care of sticks found below "standard." A greater difference in average strength values is found when the timbers are graded by this specification than when graded by specification C. The highest strength value in the culls, however, is much above the lowest in "standard" and "standard heart" grades. The lowest values found in each of the "standard" and "standard heart" grades are almost equal, as are also the highest ones. This specification gives somewhat better results when applied to the western hemlock timbers tested than specification C, but here, too, the wide overlapping of grades shows the inefficiency of the specification.

TABLE 10.—*Results of tests of 8 by 16 inches by 16 feet green bridge stringers graded in accordance with the specifications of the American Railway Engineering Association.*

Grade.	Number of tests.	Rings per inch.	Moisture.	Summerwood.	Weight per cubic foot. As tested.	Weight per cubic foot. Oven-dry.	Fiber stress at elastic limit per square inch.	Modulus of rupture per square inch.	Modulus of elasticity per square inch.
Standard heart:			*Per ct.*	*Per ct.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*1,000 lbs.*
Maximum	1	23.0	58.5	67	51.6	34.2	4,570	7,110	1,806
Average	6	15.6	43.1	43	43.4	30.3	3,927	5,777	1,477
Minimum	1	7.5	32.2	30	35.6	23.9	3,160	4,270	1,095
Standard:									
Maximum	1	27.2	64.2	55	47.2	32.4	4,580	7,050	1,788
Average	16	16.3	40.5	38	37.8	26.9	3,592	5,639	1,485
Minimum	1	6.2	27.2	25	32.6	24.3	2,875	4,170	1,236
Culls:[1]									
Maximum	1	25.8	59.0	53	48.1	31.2	4,540	6,340	1,637
Average	17	15.0	44.2	36	38.4	26.6	3,300	4,804	1,396
Minimum	1	6.1	27.6	25	33.4	24.0	1,970	2,620	1,131
Ratios:									
Standard heart						1.00	1.00	1.00	1.00
Standard						.89	.92	.98	1.00
Culls						.88	.84	.83	.94

[1] Only two grades are recognized in the specifications. Stringers which could not be included in either grade are here classed as culls.

Specification E.

Figure 13 was prepared to compare graphically the efficiency of specifications C, D, and E. The horizontal length of the shaded portions between adjacent lines shows the per cent of the total number of beams that fell between the limits of strength indicated by the scale on the left. The portions hatched from right to left refer to the highest grade material. The solid portions refer to material of the next lower grade, while the portions hatched from left to right refer to third-grade material. An overlapping of the first and third grades is indicated by double or cross hatching. The vertical columns of figures give the per cent of the total number of tests as shown graphically by the shaded areas. The grades to which the figures refer are written underneath the columns.

The figure shows that the test timbers when graded by the proposed rules fall into two groups. None of the sticks fall below second grade. There is much less overlapping between the two grades than in specifications C and D, where a large number of the sticks having practically the same strength fall in different grades. Considering that all sticks with a modulus of rupture over 4,000 pounds per square inch belong in the first grade, there is only 7.7 per cent of the test material that should properly come in the second grade. The proposed rules put 66.7 per cent of the sticks in the first grade, while specifications C and D show only 30.7 and 15.5 per cent, respectively, as first-grade material. Of the three methods of grading under consideration, the greater efficiency of the proposed rules is evident.

CONCLUSIONS.

The following conclusions are drawn from the results of tests of western hemlock:

(1) The results of tests made by the Forest Service on Douglas fir, western hemlock, and western larch show the following strength ratios for green stringers of all grades:

	Per cent.
Douglas fir	100.0
Western hemlock	88.0
Western larch	81.7

(2) The strength of beams is influenced by the size, condition, and position of knots. Knots in the middle half of beams near the lower edge have the greatest weakening effect. Knots in the middle half near the top have a slight weakening effect, while knots near the center of the middle half, or anywhere near the ends, have practically no effect on the strength.

(3) The strength of posts or columns containing knots decreases as the knots increase in size.

(4) Sound knots do not weaken wood subjected to compression perpendicular to the grain.

(5) Rot spots are serious defects in western hemlock from the standpoint of both strength and durability.

(6) Wind shakes, cross grain, and spiral grain decrease the strength of stringers in proportion to their extent; if very evident, their effect is serious.

(7) Clear, seasoned stringers of western hemlock may be expected to show 25 per cent more strength than similar green stringers. It is not advisable to depend on an increase in strength due to seasoning in stringers with defects.

(8) Large specimens tested in compression perpendicular to the grain show but little increase in strength due to seasoning.

(9) The strength of small, clear pieces tested in bending or end compression is increased two to three times by seasoning.

(10) Horizontal shear failures are much more likely to occur in seasoned than in green stringers on account of the formation of checks in the shear-resisting area (neutral plane) during seasoning.

(11) Western hemlock bridge stringers seasoned in the vicinity of Seattle for about one year will reach a condition of practically constant weight (17 per cent moisture), and in this process lose from 15 to 20 per cent of their weight, and decrease 3 to 4 per cent in volume.

(12) Measurements on small, clear specimens show that in passing from a green to a thoroughly dry condition western hemlock shrinks 5 per cent in a radial direction, 8.4 per cent in a tangential direction, and 0.08 per cent in a longitudinal direction, a total volumetric shrinkage of 13.8 per cent.[1]

(13) The rate of growth can not be depended upon to indicate the strength of structural timbers containing weakening defects. In small pieces without defects, the greatest strength was found in sticks having from 12 to 20 rings per inch.

(14) The strength of small, clear specimens increases in direct proportion to an increase in dry weight. This is also true in some degree for large timbers with minor defects, but is not the case in material with defects that influence the strength.

STRUCTURAL USES.

The demand for western hemlock both in the form of ordinary lumber and for special uses will no doubt increase when its properties are better known. At present it has a very poor market standing because of the prejudice against the name "hemlock." The lumber is practically free from pitch, has a handsome grain, takes paints and stains well, and works smoothly, both spring and summer

[1] Based on oven-dry volume.

wood standing up well to the cutting edge. It is at present manufactured into the common forms of lumber, and is also used for pulp, boxes, barrels, sash and door stock, fixtures, furniture, and other special uses. In the form of lumber western hemlock is often mixed with Douglas fir and is sold and used for the same purposes. It is only a question of time when western hemlock will be sold under its own name and on its own merits.

Table 11 shows the principal products into which western hemlock was manufactured in the States of Oregon and Washington in 1909.

TABLE 11.[1]—*Amount and value of western hemlock reported cut into various forms in the States of Oregon and Washington in 1909.*

Form.	Amount.	Value.
Lumber, lath, and shingles........feet b. m..	128,062,000	$1,309,896
Crossties [2]	2,642,000	865,000
Pulp wood........cords..	41,113	315,000
Bark for tanning extracts........tons..	1,071	14,371
Slack cooperage stock........staves..	101,000	544
Total........	....	2,504,811

[1] This table is compiled from statistics published by the Bureau of the Census in "Forest Products of the United States, 1909."
[2] Included eastern hemlock.

DURABILITY.

Authentic data are lacking with regard to the durability of western hemlock as compared with Douglas fir and other woods. The general impression is that Douglas fir is more durable than western hemlock. A few experiments made to determine the adaptability of western hemlock to treatment with liquid preservatives indicate that, as compared to Douglas fir, it offers about the same resistance to impregnation across the grain; but that it is easier to penetrate along the grain.

BRIDGE AND TRESTLE TIMBERS.

Western hemlock is well suited for use in all but the heaviest construction work, as shown by results of the tests discussed in this bulletin; but up to the present it has had a limited use in bridges and trestles. It has been used in some instances for caisson construction.

CROSSTIES.

A considerable amount of western hemlock is cut into crossties. Many of the western railroads use Douglas fir, western larch, redwood, and western hemlock almost exclusively for tie material. A large percentage of these ties are laid without preservative treatment.

POLES AND PILING.

Occasionally western hemlock is cut into telephone or telegraph poles, but its use in this form has been very limited. It has the requisite strength for pole use and grows in such dimensions as to make it

very suitable for this class of work. With a good butt treatment with some efficient preserving fluid it should give good service as a pole material.

Though practically all piling in the Pacific Northwest is of Douglas fir, western hemlock is used to a limited extent, however, for this class of work and has apparently given satisfaction.[1]

FRAMING.

In house construction western hemlock is used a great deal as a framing material. For this class of work it serves as well as Douglas fir, and locally commands the same price. Western hemlock dimension stock in cargo shipments commands a lower price, however, than Douglas fir, because of the prejudice which exists against it.

FLOORING.

Western hemlock, when cut edge grain, makes an excellent flooring material. It finishes smoothly on account of the uniform texture of the wood and it also wears evenly. It is not suitable for use in damp places on account of its tendency to warp under such conditions.

INSIDE FINISHING.

As a finish lumber western hemlock has the advantage of containing practically no pitch; it has a beautiful grain, works smoothly, takes stain readily, and, when properly dried, will not shrink or swell materially under normal conditions. It presents a comparatively hard surface and consequently does not mar easily.

LATH.

Western hemlock slabs and edgings are manufactured into lath, and as a lath material it is equally as valuable as Douglas fir or other woods. In this form there is no distinction made as to species, all pieces of a suitable form to make lath being thrown in together and used indiscriminately.

BARRELS AND BOXES.

Western hemlock is used to a large extent for barrels and boxes for shipping foodstuffs. For this purpose it serves admirably, since the wood is odorless and tasteless. Its strength and lightness also add to its value for these uses. It has some tendency to split when nails are driven into it, but this fault may be largely overcome by the use of fine nails.

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[1] A dock was constructed in Grays Harbor, Wash., in January and February, 1908. The piles used were of western hemlock, Douglas fir, and spruce from the uplands. In June, 1910, these piles were examined and it was discovered that the spruce was practically wholly destroyed by teredos and the fir badly eaten, but that the hemlock piles were only slightly injured.

APPENDIX.

TABLE 12.—*Results of bending tests of small, clear sticks of western hemlock.*

[2 by 2 by 30 inch beams; 28-inch span.]

Seasoning.	Number of tests.	Rings per inch.	Moisture.	Summerwood.	Weight, per cubic foot.		Fiber stress at elastic limit per square inch.	Modulus of rupture per square inch.	Modulus of elasticity per square inch.
					As tested.	Oven-dry.			
Green:			*Per ct.*	*Per ct.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*1,000 pounds.*
Maximum	1	40.6	98.3	54	59.5	32.2	6,560	10,560	1,794
Average	52	12.1	51.8	[1] 44	40.1	26.3	4,406	7,294	1,428
Minimum	1	5.0	28.2	29	30.3	21.5	3,120	4,560	1,097
Seasoned:									
Maximum	1	49.0	21.0	71	41.3	35.6	9,980	15,000	2,428
Average	311	19.4	17.9	47	[2] 32.4	[2] 27.6	6,333	10,369	1,666
Minimum	1	4.0	14.0	25	24.8	20.9	3,510	5,960	834
Ratios:									
Green						1.00	1.00	1.00	1.00
Seasoned						1.05	1.44	1.42	1.17

[1] Based on 46 tests. [2] Based on 307 tests.

TABLE 13.—*Results of tests in compression parallel to grain on clear sticks of western hemlock.*

[2 by 2 by 8 inch specimens.]

Seasoning.	Number of tests.	Rings per inch.	Moisture.	Summerwood.	Weight, per cubic foot.		Compressive strength at elastic limit per square inch.	Crushing strength at maximum load per square inch.	Modulus of elasticity per square inch.
					As tested.	Oven-dry.			
Green:			*Per ct.*	*Per ct.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*1,000 pounds.*
Maximum	1	32.0	106.9	62	51.6	30.7	4,150	[1] 4,640	3,051
Average	131	11.8	55.6	[2] 43	39.9	25.7	[3] 2,938	[4] 3,392	[3] 1,737
Minimum	1	5.0	29.0	28	29.8	20.0	1,720	2,270	806
Seasoned:									
Maximum	1	50.0	21.9	68	41.9	35.4	6,430	7,300	3,850
Average	463	19.9	17.0	[5] 45	32.0	27.3	[6] 4,560	5,403	[7] 1,923
Minimum	1	5.0	14.1	15	23.0	19.2	2,770	3,450	958
Ratios:									
Green						1.00	1.00	1.00	1.00
Seasoned						1.06	1.55	1.59	1.11

[1] Based on 137 tests. [3] Based on 130 tests. [5] Based on 298 tests. [7] Based on 264 tests.
[2] Based on 125 tests. [4] Based on 127 tests. [6] Based on65 tests.

TABLE 14.—*Results of tests in compression perpendicular to grain on clear sticks of western hemlock*

Seasoning.	Size of specimen.	Number of tests.	Rings per inch.	Moisture.	Summerwood.	Weight, per cubic foot.		Compressive strength at elastic limit per square inch.
						As tested.	Oven-dry.	
Green	8x16x30 inches:			*Per ct.*	*Per ct.*	*Pounds.*	*Pounds.*	*Pounds.*
	Maximum	1	24.3	64.7	55	50.5	33.8	769
	Average	18	15.6	42.1	[1] 41	[1] 42.6	[1] 30.9	516
	Minimum	1	6.5	28.2	25	36.3	27.9	345
Seasoned	8x16x24 inches:							
	Maximum	1	27.4	19.1	57	40.7	34.3	687
	Average	25	17.3	18.2	44	33.8	28.6	514
	Minimum	1	9.9	16.7	28	28.5	24.1	403
Green	6x6x24 inches:							
	Maximum	1	27.3	70.3	51	48.5	31.0	659
	Average	30	11.4	48.7	43	38.7	26.0	435
	Minimum	1	5.4	33.4	28	31.8	23.1	313
Seasoned	6x6x24 inches:							
	Maximum	1	23.5	19.6	49	40.0	33.7	670
	Average	33	16.1	16.7	[2] 40	32.0	27.6	445
	Minimum	1	8.0	14.5	35	24.8	21.4	303
Green	8x16x30 inches and 6x6x24 inches:							
	Maximum	1	27.3	70.3	55	50.5	33.8	769
	Average	48	13.0	46.2	[3] 42	[3] 39.8	[3] 27.4	465
	Minimum	1	5.4	28.2	25	31.8	23.1	313
Seasoned	8x16x24 inches and 6x6x24 inches:							
	Maximum	1	33.5	19.6	57	40.7	34.3	687
	Average	58	16.6	17.3	[4] 43	32.8	28.0	475
	Minimum	1	8.0	14.5	28	24.8	21.4	303
Ratios:								
Green	8x16x30 inches						1.00	1.00
Seasoned	8x16x24 inches						.93	1.00
Green	6x6x24 inches						1.00	1.00
Seasoned	6x6x24 inches						1.06	1.02
Green	8x16x30 inches; 6x6x24 inches						1.00	1.00
Seasoned	8x16x24 inches; 6x6x24 inches						1.02	1.02

[1] Based on 12 tests. [2] Based on 10 tests. [3] Based on 42 tests. [4] Based on 35 tests.

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